
1817

THE AUTOMOBILE BOOK

A Practical Treatise on the Construction, Operation and Care of Motor Cars Propelled by Gasoline Engines; with Full Explanations Of All the Essential Parts

By

CHARLES E. DURYEA

and

JAMES E. HOMANS

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CHAPTER I.

ANTICIPATIONS OF THE MOTOR CAR.

Anticipations of the Automobile.—The self-propelled vehicle conception is older than history. Homer tells us (Iliad, 18th Book) that Vulcan in one day framed "full twenty tripods that on wheels of gold, instinct with spirit, rolled from place to place, self-moved, obedient to the beck of the gods." A closer prediction of a modern motor tricycle could hardly have been written. Nearly three centuries ago a German proposed to drive vehicles 2,000 paces an hour by means of springs. In 1645, Patin wrote "An Englishman claims he can build vehicles that will run from Paris to Fountainbleau in one day without horses by means of admirable springs. The vehicle which is now being built will save much hay and oats, if successful." This shows economy to have been a leading thought even then. In 1759, an English doctor called Watt's attention to the possibilities of steam vehicles, but Watt did not enthuse. In 1763, Nicholas Cugnot, a French captain, designed a steam vehicle, and in 1769, assisted by the French War Department, built a three-wheeled gun carriage which was operative. In 1797, he also built and operated a four-passenger tricycle capable of four miles per hour.

Early Experimenters in Motor Vehicles.—In 1786, Oliver Evans secured a patent from the Maryland legislature, and in 1804 built, at Philadelphia, a combination steam wagon and boat for street cleaning and river dumping purposes. Numerous experiments were made in England, with the result that by 1820, or thereabouts, steam stage coaches were running regularly for public conveyance. They were large, heavy and noisy, but were winning their way into public favor, to the detriment of the horse coaches, and with such vigor that, about 1844, restrictive legislation was passed, making it necessary for them to be preceded by a man with a red flag, and imposing other annoying requirements. This legislation forced them to cease running, and England lost a great

industry, which for the past fifteen years, she has been trying to regain.

Modern Experimenters.—In 1861, Philip Dudgeon exhibited at New York a steam vehicle, and, about the same time, Lenoir, a Frenchman, patented a non-compression, 2-cycle gas-engine, ignited by jump spark, and applied one to propelling a vehicle in the next year. About 1872, Brayton, an American, fitted his patented gas engine to an omnibus at Pittsburgh and to a street car at Providence. About 1885, Copeland, of Camden, N. J., fitted a small steam engine to a bicycle, and later built two small steam tricycles. With the exception of the English work, halted by unwise legislation, as already stated, these attempts were simply isolated experiments, and were not followed by further work and successful service. While there were some gas engine and electric motor exceptions, these earlier experiments were mostly made with steam engines, and involved a complexity and weight that was greatly against their success. But, about the middle eighties of the nineteenth century, the gas engine had been so well developed that it began to appeal to a number of inventors as the proper solution, and the beginning of the present era became manifest.

The Development of the Gas Engine.—The internal combustion engine embodies a very old idea, which was once proposed in connection with gunpowder, but the high pressures, and many other difficulties involved in such use, prevented its early development. In 1844 and 1846, 2-cycle engines, air and water cooled, were patented in the United States. The Lenoir and Brayton work has been mentioned. The theory of the modern gas engine was first propounded by Beau de Rochas, a French scientist, about 1862. Otto, a German, brought out his free-piston engine in the early 70s, and improved on this in his "silent" engine, which was exhibited at the Centennial Exposition in 1876. This proved economical in operation, and crowded the Brayton engine out of the market. Its success stimulated the gas engine business, and the termination of Otto's patent protection threw the 4-cycle engine open to the world about 1886. Having a proved success before them, inventors ceased working on the 2-cycle engine, and turned to the 4-cycle. Daimler and Benz, in Germany, and Duryea, in America, early saw the possibilities of the gas engine for vehicle propulsion, and pushed it forward. Benz applied the engine as he found it, and turned out many vehicles about 1885. Daimler brought out the small high-speed engine about the same time, and is thus accepted as the "father of the gas engine automobile."

Development in America.—In America the roads were not so favorable to motor vehicles, as in Europe, with the result that the first Duryea carriage was not built 'till 1892, although begun in 1891. Another was finished in 1893. The

first Haynes was finished in 1894, and the first Winton in 1896. All of these were propelled by single cylinder engines, but were the beginnings of lines since continuous, and, therefore, must be counted as successes. The first double-cylinder Duryea was made in 1894, and the first double-cylinder Haynes in 1895. An enterprising French journal held a contest in 1894, at which an average speed of eight miles per hour was shown. The success of a similar contest in 1895 attracted the Chicago "Times-Herald," which offered $5,000 in prizes and a gold medal for a similar contest at Chicago on Thanksgiving Day, 1895. Eighty-three entries, some foreign, were received. A Duryea car won the contest, made extremely difficult by a foot of crusted snow on which pedestrians walked without breaking through. One foreign vehicle managed to cover the course that day while another finished next day, thus clearly showing the inferiority of foreign constructions at that time. A second contest was held at New York on Decoration Day, 1896, for $3,000, offered by the Cosmopolitan Magazine, and was won by three Duryeas, the foreign products not being able to return unaided.

The London-Brighton Race.—A further evidence of the superiority of the American products was given at the first event in England, held November 14th, 1896, to celebrate the repeal of the restrictive road laws of 1844. Nearly fifty entries including the first, second and third winners of the French racing events of that year, were present, and all were beaten by a Duryea, nearly an hour, in the distance of 52 miles from London to Brighton. This unique victory of an American automobile over the best foreign constructions stood for years as evidence of the advanced positions of American constructors. Pneumatic tires, artillery wheels, spray carburetors, electric ignition by mechanical generator, throttle control, and many modern features were first shown on those winners, and contributed to the result.

Electric and Steam Vehicles.—A practical electric vehicle was exhibited by Sturges at Chicago in 1893, and the first of an electric line was entered by Morris and Salom at the "Times-Herald" contest of 1895, although unable to compete under the severe road conditions. About 1896, Whitney made a light steamer, and, at the Mechanics Fair in 1898, a number of such vehicles were shown at Charles River Park near Boston, at which time the Stanley steamers first came before the public. These were offered at an unprofitably low price, and found many buyers. Makers took up this type, and thousands of them were marketed, making the real opening of the automobile business. They proved to be toys, however, very expensive to maintain and difficult to operate, and the business quickly toppled, to be followed by the more slowly and safely developed gasolene car, which has grown since to such wonderful proportions. The electric vehicle, while always having a field, never had much following. In

the early years "electric" was a word to conjure with, and the general public was not interested, if it was not "electric." The cost and weight of this type of car limited it greatly and caused it to be almost ignored, but in the largely-expanded business now existing the electric finds a considerable field, and is coming rapidly to its own.

CHAPTER II.

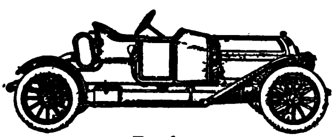
SELECTING A MOTOR CAR.

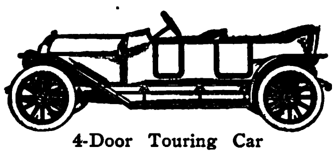
Selection of the Car: Beauty.—A popular automobile instruction book should include practical hints on the selection of the vehicle. Proper or improper selection too frequently determines whether or not the after-service is satisfactory. Heretofore appearance has probably decided more purchases than any other factor, while speed and quantity have followed as close seconds. Fitness for purpose and quality have been neglected, although plainly of greater importance. Fortunately, at present the buying public is better informed than in the recent past and these errors are less frequent. Style is a matter of usage, and is created almost wholly by advertising. It bears no relation to beauty and may change with the seasons, leaving dissatisfaction with one's once stylish choice. Ample examples of this fact abound. Of real beauty, Ruskin says it " is not a matter of individual whim or caprice, but consists of certain essential factors, the chief of which are fitness and truth." He also says, "Architecture does not begin 'till the utility of the structure has been fully provided for." Sweet says, "To the educated eye that which is right looks right." This and many similar expressions by various authorities show that " pretty is that pretty does," and that utility is the real basis of beauty.

Speed and Ease of Control.—Speed, once a test of quality, has become so common as hardly to attract attention, while its abuse has put it under the ban of the law. The experienced driver takes pride in the " sweet handling " of his vehicle rather than in excessive speed, recognizing that any greenhorn can open the throttle and let the vehicle race, but that skill is necessary to start smoothly, shift gears noiselessly, and stop gently, with no damage to tires or vehicle, and with greatest comfort to passengers. Makers are recognizing these truths, and are not gearing their vehicles so high as formerly. Also, they are providing better carburetors and speed controls, so that it is no longer necessary to keep

the engine at full tilt, lest it stop, but allow the driver, if so inclined, to slow up for bad crossings, just as if driving a horse. The same use of the automobile brings greatest pleasure, and the few occasions when great speed is wanted come so seldom, that it is a mistake to give prominence to speed in buying. Practically every vehicle made has speed enough for all practical purposes.

Size and Power Required.—Much the same reasoning applies to mere bigness. So long as the mere possession of an automobile was a vulgar proclamation of one's standing in the community, the addition of another cylinder, or an increase in the length of the wheel-base, by a foot or so, had some significance; but to-day, since people have learned the advantage of the light handy automobile for runabout and business purposes, and since many people, keeping a big touring car in their garages, are using the runabout or the motor buggy for short trips or few passengers, this foolish excuse for buying a heavy, clumsy, expensive car no longer exists. The many varieties and sizes of automobiles now offered leave one quite free to exercise his best judgment, and he should select that


Roadster


4-Door Touring Car

which best fits his need. It is wiser to have the wrong size a few times in the year than most of the time; just so, it is better to buy for the daily needs, rather than for the holiday needs. The sight of a touring car doing business errands is not edifying. It is better practice to overload the runabout for an occasional trip, made with careful driving, than to have the expensive touring car, with empty tonneau and heavy weight, lying idle, because it does not meet daily needs. This should make the thought clear. Select the car for the service to be done. Whether it be a limousine or a town car, whether a touring car or a high-speed roadster, or whether a runabout or motor buggy, let it be selected with reference to the service for which it is to be most used.

Roads and Wheel Sizes.—And this thought must also include the roads. If the roads are good, the wheels may be small, but the steady increase in wheel sizes should plainly indicate that there is merit in large wheels. For rough roads, particularly, the wheels must be large and the clearance sufficient to enable the rig to get over the ridges or obstacles, such as rocks or stumps, without striking. The sight of automobiles stuck because their fly-wheels or framing or sim-

ilar important parts drag the ridge in the middle of the road, or when the wheels are in ruts, is not complimentary to the judgment of either maker or buyer, yet such sights have not been uncommon.

Size of the Tires.—The tires should be large. Some makers are beginning to recognize that large tires will give little trouble, and need few repairs, particularly in connection with a light vehicle. If there is a choice, let it be in favor of a large wheel with narrow tire, rather than a small wheel with wide tire, for the wide tire rolls over more surface, and picks up more tacks, as well as taking more power. The small wheel also drops into holes more abruptly and roughly, and strikes obstacles more severely. The difference in wheel sizes is quite marked, and comparison on the road of the earlier small-wheeled cars, with the later ones, having large wheels, will make this difference plain.

Selecting the Engine.—Next to the choice of bodies and wheels, comes the selection of the mechanism. Here there is a wide range, but the buyer will usually be satisfied with

Single Brougham

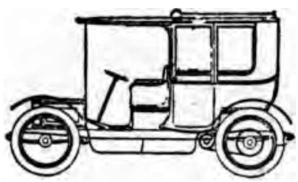
Three Quarter Brougham

consideration of the engine; whether 2-cycle or 4-cycle, and whether of two, four, or six cylinders; also, whether air or water cooled, and a number of minor considerations, such as how oiled, how regulated and how ignited. Most of these features will be considered in another chapter. In general, simplicity is the correct guide. If the motor does the work satisfactorily, as indicated by trial, the fewer the number of parts the better. Of course, for extremely smooth running, and for large powers, the greater number of cylinders is to be preferred, but the larger sale of the smaller vehicles having but two cylinders, as compared with the sales of six-cylinder cars, indicates that, value for price considered, the advantage lies with the simpler form. The four-cylinder engine has a very great popularity and is the "golden mean," at present, and, therefore, safe to buy, without question. The 4-cycle engine has been so well developed and perfected, that it is doing splendid work, but the two-cylinder 2-cycle gives the same number of impulses per revolution and so is far simpler. That it will in time win a leading position is believed by many.

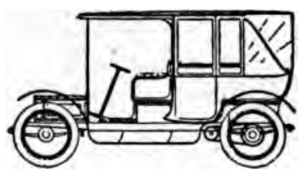
The Cooling System.—Water cooling is the accepted form, and has been well worked out. Natural water circulation is gaining in favor, and fly-wheel fans are on the increase. But air cooling does anything that water cooling does, has fewer parts, and is free from winter worries. That it will win its way to the front seems impossible to deny. The principal argument against it is that it is less costly, and has been oftenest fitted to cheap, unsatisfactory cars, thus getting blame which it did not merit.

Lubrication and Lubrication Methods.—Lubrication methods are being simplified. The force-feed oiler and pump of a few years ago, with its multiplicity of pipes, has given way to a constant level splash system, using a pump to keep the level, and feed a few of the important bearings. Simplicity is winning here, and it is safe to look with suspicion on a complex oiling system.

The Ignition System.—Magneto ignition has become all but universal. Whether this will survive the simple and eco-



Limousine



Landaulette

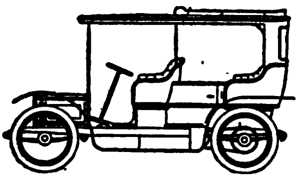
nomical single battery spark methods is difficult to foresee, but probabilities seem in its favor.

Methods of Transmission.—The main thought in choosing a transmission is the service required. If the engine is small and the car heavy, it is best to choose one with several speeds. But if the engine is powerful, and the car light, practically all work will be done on the high gear, and a low gear for emergencies is all that is needed, besides, of course, a reverse. Likewise, if the car is to be used for speeding, the engine may not be able to turn fast enough for the speed desired, so a very high gear is required. This is why some cars are fitted with three and four forward speeds, while others have but two. It is evident that a car, designed for not over thirty miles per hour, can get along with two speeds forward, just as well as can a car to do sixty miles per hour, with four, weights and loads being equal; also that a 1500-pound car, with two speeds is practically as well equipped as a car weighing twice as much, with four speeds.

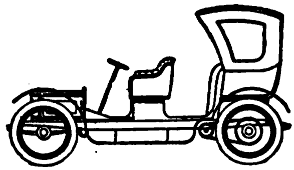
The Engine and the Transmission.—It will also be evident that the heavy car can have a larger engine, and so make

up for the smaller number of speeds, but the engine cannot turn faster in one car than in another, so a wide difference in speeds should be provided for by an increased number of speed changes in the transmission.

Selecting the Transmission.—In connection with transmissions it is not clear that there is any great preference. Most makers have well worked out their transmission sets, and they are giving good satisfaction, consequently, the buyer is usually safe, no matter which style he chooses. The least complicated forms, in the most accessible locations, are the ones to be favored. The single universal joint in the shaft drive seems to be gaining ground. Friction transmissions also have gained ground, and become more numerous. As vehicles become lighter, it is likely that the friction drive will become more prominent. An old form of friction, new in the automobile line, termed the roller drive, has proved very satisfactory for light work, and is the extreme of simplicity.



Open Limousine



Hansom

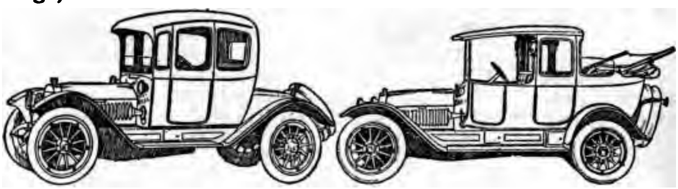
Steering and Transmission Control.—The levers for controlling the transmission have usually been mounted on the right side of the vehicle, but, with a growing demand for left-side position of the operator, there are many examples of left-side mounting. A simpler and more direct plan is to mount these levers in the center where they can be reached from either side and this arrangement permits the maker to furnish control from either side with the minimum of changing. This central carrying of the control levers seems likely to become more popular and is worthy of consideration.

Wheel and Lever Steering.—Wheel steerings is the most popular form, and the one particularly adapted to speed or straight-away service, but for city, or short-trip use, the lever, as used on practically all electrics, is most handy. The impression that lever steering is not suitable, except for the lightest vehicles, is incorrect, as this electric usage proves. The handiness with which one can mount with a lever puts it far ahead of the wheel, while its action is quicker and surer in city and close driving. That it need not be feared for speed work is proven by the fact that the Stanley steamer which made the fastest straight-away mile some years ago, at Ormond Beach, was a lever-steered car.

Tops and Protective Devices.—Tops and wind protections are almost universal, and attest the daily use of the automobile regardless of the weather. A wide variety of material is used for tops, and so, a considerable range of price and choice is possible. In general the leather top is most durable, but the substitute tops are lighter, and represent better value, expressed in appearance and service.

Trimmings and Auxiliaries.—In trimmings, the novice is quite likely to blunder. Usually he fits the car with so many gewgaws that it looks like a plumber's shop. This tendency is slowly passing, and the modern dash is reasonably clean. Needless things should be left off. They can be added at any time. The beginner usually will have enough to do to master the necessary things, without having to pay attention to these that are unnecessary. The older users seldom fit their cars with such things and the beginner will do well to omit these marks of the novice.

Trimmings and Metal Finishes.—In general, it should be kept in mind that the automobile, big or little, is one's carriage, and should be selected and fitted as one would a horse



Coupé Landaulet

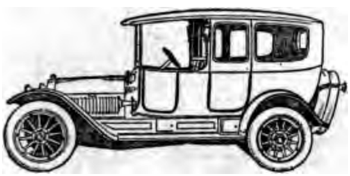
equipment, when in doubt about certain features. This thought calls attention to finish. Too many automobiles have been masses of brass, taking much time to keep them clean, and not easily to be cared for by turning on the hose, as is a horse carriage. Fortunately, the use of japanned, or black nickel, or other forms of oxidization, are coming into favor, and doing much to lessen the care and attention needed. Polished nickel is much better than brass.

The Quality of Metal Trimmings.—As to quality, much must be left to the maker. It is largely impossible for the buyer to judge of the quality of the metal used in his car. He can form some opinion of the workmanship and quality of the trimmings, but, in general, he must depend on the honesty of the maker, and, therefore, should buy of makers who, by making good goods, have built up a reputation for honest product and fair dealing.

Reputation of the Builders.—Long experience in manufacture, a reputation for consistently continuing a line of goods, and a record of satisfaction from the users are the strongest recommendations. First year models of any maker,

but especially of new and inexperienced makers, should be avoided. It is a well known fact that they usually are not perfected in every point, until the usage of the first year in the hands of the public has shown the weak or unsatisfactory points, that even the most strenuous testing of the maker failed to bring out. This is not a condemnation of new things. The buyer should ever be alert for new things, also independent enough to decide for or against them, as well as willing to give them a fair trial; but the beginner will do well to leave such things till he has gained experience with the old and proven, and is qualified to pass a sound opinion on the new. Progress is usually made by stepping from the old to the new, and not by ignoring the old.

Considerations in Purchasing.—In conclusion, the buyer should consider, first his needs, and let them indicate the style of car; next the roads, and select accordingly; then choose weight and size, according to the amount of money he is willing to invest, both in the original purchase, and in maintenance; and, finally, select neatness and simplicity, remembering that "beauty unadorned is adorned the most."



Limousine

Berline

Many buyers mistake in making their first purchase, because of their assumption that, once the owner of a car, one's expenses cease: thus they go beyond the financial limit that should govern them. The car does not eat hay nor oats, nor does it need a veterinarian, but there are involved expenses which should not be forgotten. Fuel and oil, tires and tire repairs, batteries, and machine repairs represent a total fixed expense not to be ignored. Add to this the possibility of accidents, and major repairs, and the cost of garaging, or attendance, for care and cleaning. Under garaging comes the opportunity for a man to save much money and annoyance by doing his own attending and repairs. If he will do this he gets better acquainted with his vehicle, and becomes its master. And he will get a satisfaction from its use that does not follow the mere handling of the levers, without knowing the why and wherefore, and the perfection of operation following the knowledge that every part is in good running order.

Fitness for Special Service.—To follow these general remarks on selection by more specific advice, it is necessary to

consider the various kinds, sizes, powers and speeds presented to the purchaser. For fine city streets, and for service where time is not important, but simplest operation and least skill enters, the electric is suitable, and finds many users. At first, when bought by those wanting the speed and excitement of the new sport, it was a disappointment, but, of late years, bought by those who wish to get about the city in a comfortable, clean, dignified manner, and who do not mind the delay and bother of having the battery recharged, with the consequent expense in money and time, the electric is giving splendid service, and its use is rapidly extending. The heavy weight requires strong construction and the batteries are liable to depreciate rapidly, but, when ready, it is ready, without starting, fire, water, spark or carburetor adjustment, or any of the little details incident to the more common gasolene car. Throw the switch, shift the controller and steer is the sum of the operating requirements, in addition to the brake.

Thoughts on Steam Cars.—The steam cars, fewer in proportionate number than in earlier years, need no starting, when once steam pressure is attained; but they have an open fire to be taken care of, a steam boiler to be fed with water, and they use much more fuel per mile than the usual gasolene car. While their ills are seldom such that one cannot get home with them, they require considerable attention, and are favored only by those who are mechanically inclined, or who have had a steam engineer's education. They are splendid hill climbers, and are able to negotiate bad roads in a surprising manner. The old argument that "everyone understands steam" is not of particular force nowadays, when almost every boy has an inkling of the essential facts concerning the gasolene automobile engine. The flexibility of the steam engine makes driving one much like driving an electric, but in this respect the gasolene cars are better than in the past. There will always be some who prefer steam, but their number is so small that much space need not be devoted to the steam car.

Advantages of the Gasolene Car.—The gasolene car is built in such a diversity of sizes of bodies, and of engines, and in so many styles, that it meets the needs of practically every class of buyers. Self-starting engines, seat-starting devices, and similar refinements, do away with much of the worry of getting the engine started that beginners once feared. Magnetos or single-spark devices make the ignition quite certain, and the wiring so short that there is little danger of going wrong and stranding, because of an obscure electric leak. Carburetors have been well perfected. In fact, every part has been so well developed that no one need fear the "mysteries" once believed to exist in, or around, the gasolene car. The simpler forms surpass even the electric for simplicity, while the light weight puts the maintenance expense far below that of other systems. The wide range of choice in gasolene-car

types is not to be found in others, and runs from the motor bicycles, through tricycles, to the light motor buggies and small runabouts. The high power runabouts are but stripped forms of touring cars, while the town cars, limousines, and similar vehicles, may be also modified forms, or special designs, adapted to some particular service.

Power, Size and Speed.—The city car, and one for moderate speeds, should have a moderate wheel-base. The long wheel-base is for speed, and detracts from handy service in bad roads or narrow streets. Power is necessary for speed, but for usual service low gear-ratios often are more satisfactory than large powers. The low ratio permits the engine to do its work, without laboring and jerking the mechanism, and permits the operator to get about with the least gear shifting bother. If properly geared, the usual gasolene engine will take its car over any ordinary road, without changing gears. This is why so much talk is heard about taking the hills "on the high." With a properly flexible engine, the high speeds, that may occasionally be wanted, can be had by letting the engine turn at an unusually high rate of speed. This permits economy, since, during most of the time, the engine is not working at its full power, and can burn very lean mixtures, while, since it is not often used with the low gear, it does not run at excessive speeds, and so use fuel rapidly. The dying of the "speed mania," and a better recognization of actual service by makers, is tending toward lower gears and sweeter service, from the gasolene engine, and the buyer will do well to keep this in mind.

CHAPTER III.

PRACTICAL POINTS ON MOTOR CARS.

Delivery of the Car.—The first thing to do, after getting an automobile, should be to get acquainted with it. If possible, have it delivered where you can choose your own time to start it. Many a user's troubles have begun with the arrival of a fine rig at the freight station, where everybody in town could come to watch him have trouble, and show his ignorance. And not a few of the spectators have been envious enough to wish that he would fail "to make it go" properly, while others, at least, were quite willing to enjoy to the fullest any amusement which they could derive from his lack of experience. Under such conditions, few men can retain their self-control and reasoning faculties to the fullest, and quietly make sure of doing the right thing or nothing. As a result, one may race the engine needlessly, drop in the clutch with a jerk, strip or strain gears, lose control of the steering and strike something, start off with a tire flat, or forget to fill the oiler or water system, or do some other wrong thing, which amuses the crowd and mars a good machine. Many a vehicle and its maker have been unjustly blamed for the results of such conditions.

Need of Instruction and Experiment.—Much better is it to have an experienced man start up the vehicle, and drive it to some place where you can study it alone, and at your leisure. But if the experienced man is handy, you will not need these instructions, for he will do the teaching better than any book. In his absence, better have the vehicle towed to your place or take delivery at so early an hour that few loafers are about. Or, remembering that they know even less about the matter than you do, simply ignore them, and take your time. Above all do not invite your friends out for a ride till you have had several satisfactory rides by yourself. Because the car obeyed the will of the demonstrator like a trained horse, there is no reason for you to believe that all you have to do is to look wise. As well invite them to hear

a piano recital on a new piano, when you have never taken a lesson in music. They will respect your judgment, if you hold them at bay 'till you have proven the new car for yourself.

Examining the Tires.—On receiving a new car, first examine the tires. These are very expensive parts, and quite likely to be damaged, or deflated, in shipment. If damaged, enter a protest, and accept the goods from the freight carrier, only after the damage is noted in writing by the agent. This applies to other parts, as well as to tires. You cannot support a claim for damage if you have already given a clean receipt. If you leave them till the last you are very likely to start off without attending to them and damage them.

Water and Oil Systems.—Next make sure that there is water and oil. If the weather is warm the car will probably be shipped with water in the system, and there is usually oil sufficient for a short run, at least, but, by inspecting, you will be sure. You cannot run without fuel so leave it till the last.

Inspecting the Fuel System.—Inspect the gasolene line, and shut any cocks that may be open, either at the tank bottom, or at the bottom of the carburetor. Otherwise, you may lose much fuel with danger of fire by its running out of an open cock, nearly as fast as you put it in. Depress the float of the carburetor by the means commonly provided, so as to know the fuel has reached and filled the float chamber. Also, examine the carburetor, so as to find how the throttle works. If you cannot determine this, you will need to set the throttle lever at mid-position, and determine the proper way to move it to control by trial, after the motor is started.

Brake Levers and Pedals.—Often the brake levers or pedals are marked, but more often not. Try these levers and see what they move. Get the effect of their movement fixed in your mind, so that, when you desire a given result, you will know how to produce it. To know that a certain lever, if pushed, produces a certain result, will enable one to drive a car much as a parrot talks; but it is not the safe, intelligent, artistic way, and should be avoided. Too many drivers are of the parrot type, and seem to think that they can handle a car best, if every desired result has its own lever, which only needs to be pushed. Skilled drivers know that such a control is not easiest, nor best, and it is certain that a beginner should avoid such a habit. The same is true of the clutch pedal, or lever, and the gear changes. Learn what each is before starting to drive.

Testing the Spark System.—Next investigate the spark system. This will doubtless be properly wired, and ready for use, except that the battery wires will doubtless be discon-

nected somewhere. They must be reconnected. The switches will also, likely, be open or "off." Before throwing them "on" investigate the spark lever position. It should be retarded; set "late" with reference to the engine motion. The engine direction can be seen by feeling of the starting crank. It has ratchets and will turn the engine only one way. As it turns, note the way the timer or distributor turns. "Advancing the spark" moves it further the reverse way. Retarding moves it in the same angular direction. If the weather is cold and the engine stiff, because of the cold cylinder oil, "prime" it by squirting into each of the cylinders about a thimbleful of gasolene. Priming cups are usually provided, but, if not, the spark plugs can be unscrewed. Do not do this, if it can be avoided, lest you fail to get the wires again connected properly. A beginner should be particularly careful not to change things. The maker knows his business, and the best results will be found by leaving things as the maker intended.

Cranking the Engine.—Next, throw on the switch, and pull up on the crank. Be sure, before doing this, that the spark is retarded, and the clutch not engaged. It is well to look at these two important things, after the switch is thrown on, to be sure that they are not wrong, when you pull the engine over. As the engine turns over one compression, listen for the buzzing of the spark coil, if a buzzing coil is the kind used. This will assure you that you have a spark. If the engine does not start with three to five pulls each over a compression, do not keep pulling. Hunt for the cause of the trouble. Look again to the fuel supply, the position of the throttle, the wiring of the electric system. If the conditions are right, laboring at the starting crank is unnecessary. If they are not right, it is a poor way to remedy them. If the engine fails to "fire," and there is a proper spark, it is because there is not enough fuel, or because there is too much. In cold weather, or with a cold engine, the fuel does not easily vaporize, and so there is usually too little. But with a warm engine, even a little fuel may prove to be too much.

Testing the Fuel Mixture.—This can be tested by removing a spark plug, and holding a lighted taper, or match, well down in the hole. If the mixture is too little ("lean"), it will not ignite; if too much ("fat"), it will ignite, but burn slowly and with a yellow flame; if about right, it will ignite, and blow out of the hole with violence and noise. In making this test, be sure to keep the face and fingers out of the way of the flame, which will extend a foot or two, and is so hot, that it is liable to burn one's fingers badly, and singe one's face and hair. Usually, it is not necessary to make this test. By turning the engine over a few times, with the priming cocks open, the fat mixture will largely be replaced with pure air, and, if the spark is on, the explosions should manifest

themselves, as weak "spits" through the cocks, gradually becoming stronger, as the mixture becomes better. When the "spits" are vigorous the mixture is still too fat, because the air admitted through the cocks allows it to ignite, but it will probably suffice to run. Close the cocks and try again. When the engine starts nearly, close the throttle, and slightly advance the spark. Do not let it race, but keep it running till warmed up.

Smoke from the Exhaust.—In the mean time, notice the smoke. If blue, it indicates vapor of lubricating oil, also probably, that the oiler has been feeding, while the engine has not been running; or that the oiler is feeding too fast. This is of little immediate importance. But if the smoke is black, the presence of an excess of fuel is practically certain, and the carburetor may need adjusting. If, as the engine warms up, it seems to get weak and lazy, this, in connection with the black smoke, is sure proof of an excess. Note where the carburetor adjusting needle stands, and turn it so as to feed less. If you make a mistake, you can turn it back to the original place. If there is no smoke, but a decided pungent odor, either too fat a mixture or misfiring is indicated. If the latter, the engine will not run steadily, purring like a cat, as it should, but will jerk, more or less. In such an event, the mixture may be too lean, and the carburetor needle needs opening.

Importance of Correct Adjustments.—In general, the beginner must be careful of adjustments, till he is sure he is right. When cold, the operation is not the same as when the engine warms up, and, in trying to better a carburetor adjustment at starting, one may make it worse for running after a few minutes. Having become satisfied that the engine is not in danger of stopping, because of too little, or too much, fuel, the next move is to learn to throttle. Try the effect of moving the throttle lever forward and back. Associate the action with the effect. As the throttle is opened, the engine should speed up. Do not let it continue to race, but immediately shut it off. The only object of letting it speed up is to get used to the effect, and to be sure that it does not choke down from excess fuel, as it starts to speed up. High speed is a strong cause of engine trouble. Never race the engine needlessly. It can no more last long at racing speed than can you yourself. If quite cautious, the engine may be stopped, and again started, till one is sure of the ability to do this at will.

Operating the Clutch.—The next step is clutching and driving. With a sliding gear the clutch is in engagement at all times, except when declutched, for the purpose of shifting gears, and is engaged with no effect when the gears are neutral. It gives the same result, as if the clutches of the planetary, independent, friction or roller systems were not

engaged, and is so treated in this article. To drive one must, with the sliding gear, withdraw the clutch, engage a set of gears, and then gently, very gently, let in the clutch. The beginner should be sure that he engages the low speed gears, so that the vehicle will not start moving at a speed beyond his ability to control it. In the other types the theory is the same, except that the clutch action does not include withdrawal, for the clutches are not engaged, except when the driving of the vehicle is desired. As the engine begins to feel the load of the vehicle, the throttle should be opened, so as to avoid pulling the engine down. As the vehicle begins to move freely, withdraw the clutch, and slightly apply the brake.

Declutching and Braking.—This to get accustomed to the effect of declutching and braking. There is no necessity to fully stop the vehicle, but simply to go through the needed actions, so as to fully accustom the feet to act with the brain, in the work, and, as quickly as possible, make the action of declutching, followed by braking, as nearly automatic as possible. No driver is safe till he has, by practice, become automatic. In a crisis, he becomes rattled, and cannot think what to do, even if he has time to think. He therefore, does only those things which have become automatic with him. This is why the service brake is the only safe brake in emergencies. It will be applied, because it is second nature to use it, when one wishes to stop. The emergency brake will almost certainly not be applied, and too often faith in the emergency brake has been misplaced.

Practice in Steering.—During the practice just described, some steering has been necessary. How much has depended on the space at hand. By letting the car run in a circle a very moderate space will permit much practice and require no steering. A pasture, a race track, a little-traveled wide street, or some similar place, where there is little to run into, and few to discommode, is the ideal practice ground. Having fairly well learned to clutch and declutch, as well as to throttle the engine, some driving should be tried. In this do not aim to run straight, but practice turning, first to one side, and then to the other, thinking, and doing just as you think. In this way, will steering become "second nature." Notice that, with steering wheels, or cross levers, the motion of the hands is the same, as if they grasped one or the other, or both, of the hub ends of a front wheel. With tiller steerings, the motion is the same as the back of a wheel, or the same as a boat tiller; *i. e.*, in a direction the reverse of the desired vehicle direction.

Make Haste Slowly.—Be in no hurry. Any body can throw in a gear and open the throttle, but mishaps, encountered while learning, sometimes destroy confidence for *years*. Also make the lessons short. Twenty minutes' hard

learning is enough at a time. Stop and look the rig over a while. Study again the various things already learned. Then repeat.

Practice in Gear-Changing.—As soon as driving becomes a matter of some certainty, try a higher gear. This brings in gear-changing. With the planetary, and some other gears, there is no knack to be learned. The gear-changing operation is so simple that it cannot be done wrongly. But, with the sliding gear, some skill is required. To hold the engine from racing, when the clutch is out, and to catch the next speed, without grinding the ends of the teeth off the gears, is a matter requiring some practice and judgment. It must be learned by trial. The proper speed, the time allowance for the vehicle and clutch speeds to get together, and the proper amount of energy to apply to the gear shifting lever, to cause the gears to jump into mesh, without noise or damage, become matters of intuition. In reversing, this is more true than in forward work for the movement of the meshing gears is in a different direction. And in reversing, a neat driver will coast forward, while changing the gears, and, as the car comes to a stop under the brake, he will apply the clutch to, at once, start it backward. This should be done very gently, never letting the clutch in full, but always standing ready to withdraw it and check the backward motion of the car.

Things to Avoid.—Let no expert demonstrator impress you with the idea that spectacular rushes forward, or backward, right up to the stopping place, followed by jamming on the brakes and sliding the wheels, is good driving. Such exhibitions resemble sane driving about as much as tight rope walking resembles decent pedestrianism. The wise and skilled driver, handling his own vehicle, does it sweetly and without unnecessary power, or brake application. He aims to coast up to the stopping point, letting the movement of the car die easily and gracefully, and, likewise, he prides himself on getting away easily, and without a shock. Letting one action glide into another sweetly is the essence of good driving. On a hill, particularly, is where this is made manifest.

Hill-Climbing.—The good driver holds to his high gear, till the engine is seen to be laboring; then the gears are shifted, as the engine, released from the clutch, speeds up, and, as the speed of the engine reaches the new relation-ratio, the clutch is let in and the engine takes the load, without the car having perceptibly slacked speed, or, without having received a jerk. It is possible to shift so quickly that the car is forcibly retarded by the gears, while the engine is gaining speed; or, what is more common, to let the car come to a standstill, and require starting again. Both are evidence of bad handling, and un-expert drivers.

Principles of Good Driving.—On the road the matter of speed control should be studied. To rush from start to finish, as fast as the engine will carry the car, is not driving, although many novices seem to think so. Always to have the car under control is the first requirement. Never, under any circumstance, drive at a speed in which you do not feel certain that you are in full control of the car, and can turn, or stop, before damage can result from any cause that is, or may likely be, in sight. This means, know your brake, your throttle, and your engine. Know, by trial, how much space you need to stop at certain speeds. Learn to know what resistance the road offers to your progress, and how much you can rely on it to help you to stop. Slow up in bad spots, or at corners, where you cannot see who is coming around the bend. The driver who takes chances that no other car will be coming the other way at such times will, sooner or later, meet with disaster. There is ordinarily no call for such risks. The long array of accidents each year from this neglect prove the folly or criminality of such driving. Take the uphills as fast as you like. If the mechanism goes wrong you will stop by gravity. And as the vehicle comes to a stop, set the brakes to hold it. If they are disabled, turn the vehicle across the road. In climbing bad hills, it is wise to watch the gutter, and be ready to back into the safe one, if, for any reason, the car becomes disabled. A plan thought out, before it is needed, is much safer than trusting to luck after.

Coasting and Braking.—Many rush the down hills. This is bad practice. A lost control and gravity make the matter worse. Particularly, remember here always to keep the rig under control. Cultivate controlling by more than one method. Learn to stop by stopping or throttling the engine. Learn to control by the spark advance, or by shutting down the gasolene supply, as well as by the throttle. Learn to brake with the engine. These things all enter into the full mastery of the car, and one does not get the highest pleasure nor utility, till he is master of his vehicle. You may not have need for all of these abilities, but the man whose float has become leaky or soaked, and will no longer float, may drive home in comfort if he is able to control the fuel supply. Brakes were so inefficient for years, and new drivers blamed the brakes so often for their own incapacity, that most cars have two sets of brakes, but, if for any reason, they should be out of commission, the ability to make the engine handle the car down hill, as it must do up hill, is a valuable accomplishment.

CHAPTER IV.

AUTOMOBILE MOTORS.

Requirements in a Perfect Motor.—The ideal motor would be one that could vary its torque, or ability to turn its shaft, inversely as its speed. Thus a ten horse-power motor ought to be able to pull as large a load as ten horses out of the mud, at one-horse speed, or pull the load of one horse at the speed of ten; that is, ten times the speed at which one horse could pull it. The horse comes most nearly to this ideal requirement. He can, for a few minutes, exert several horse-powers; just as a man can, for a few seconds or even a minute, exert six or eight times the average working power of a man, and do work equal to the average horse rate. To make this clear, let us first define what is meant by a "horse-power."

Meaning of Horse-Power.—When Watt began to market engines for hoisting coal and pumping water from the mines, he had to have some standard for expressing their ability. He knew how many pounds of coal a horse could hoist at his usual rate of working which could be kept up all day. This had been determined by the use of many horses, and striking an average, which showed that a horse can raise 550 lbs. one foot per second, or sixty feet per minute; or that he could, by proper arrangement, of the pulleys raise 33,000 pounds one foot per minute. In short a horse-power is 33,000 foot-minute-pounds. But a horse can only pull about a certain amount, no matter how slow the load moves, and he is not able to move it faster than his fastest rate, no matter how easily it moves. The ideal motor should be able to convert its power-equivalent into pounds moving at a small fraction of a foot per minute, or into feet per minute, even if exerting only a fraction of a pound of pulling or lifting effort. No motor has this wide range, and, therefore, some sort of gearing is used, to attain, more or less fully, this desired conversion. Such devices will be considered under "transmissions."

The Automobile Electric Motor.—The electric motor is most nearly ideal of all mechanical motors. In automobile practice, it is fed from a battery consisting of 24 to 100 cells. Suitable wiring and controlling devices are provided, so that the current may be led to the motor, producing effects 100 cells strong (intensity or amperage) and only 1 cell fast (pressure, voltage or E M F), or 100 cells fast and only 1 cell strong. The actual arrangement differs in different electric vehicles, but this is the principle which enables the electric motor to turn with great force at low speeds, or to run at great speeds with little force. The shape and construction of the motor favors this wide range also. It has but one main moving part, the armature, which constantly rotates, and its shaft may be used to drive the vehicle or other connected machinery. Since it has a rotary motion only, it may be run at high speed, without vibration or noise, and by shifting the direction of the current it may be reversed. It will start itself, and the vehicle, with great power from a standstill, and is easily controlled. Its great drawback, however, is the battery, which is the only available source of current for vehicle use.

The Automobile Steam Engine.—Next in ability as a motor is the steam engine. With it we must have a boiler containing steam, usually under a limited high pressure. The later and better vehicle boilers are capable of very high pressures, and can generate steam very quickly. Although they can furnish steam at high pressure, the quantity does not vary, as in the case of the battery. High pressure usually means a hot fire, rather than a small quantity of steam. Likewise, when the pressure is low, the quantity is not greater, but is too often limited. The engine proper is a cylinder, containing a piston arranged to reciprocate from one end to the other, and back again, as the steam, let in by suitable valves, pushes upon first one face and then the other. The usual steam vehicle engine has two cylinders, whose connecting rods push on cranks set at right angles to each other, so that one crank or the other is always where its piston can exert power on it. Such an engine does not get on dead centers, and requires no fly-wheel. The full boiler pressure of the steam can be turned into the cylinder, so that the engine will start its load from a standstill, and will pull as slow as may be desired, but with considerable force. If a variable cut-off is provided, the steam at full pressure may follow the piston the full length of the stroke for great power, or may cut off at one-fourth, or similar small part, of the stroke, and expand, with decreasing pressure and power, but with increased economy, to the end of the stroke. At the end of the stroke the exhaust valve opens, and lets out the exhaust steam, followed by admission of new steam to drive the piston back again. This admission at both ends of the cylinder constitutes a double-acting engine. If the pistons are light and well balanced, the steam

engine may run at high speed, and is seldom provided with a change-speed gear (transmission). Its perfect control, freedom from noise, good starting ability and great speed capacity make the steam engine a favorite with many.

Superiority of the Gas Engine.—Like the electric motor, however, the steam engine has one great fault. Both are tied to their sources of power; in the one, the battery; in the other, the boiler: both objectionable, because of weight, space occupied, and need of attention. The gas engine is not so hampered. Much more complex in theory, and rather more complex in construction than the electric or steam motors, it is still the simplest when the entire power plant is considered. It has no boiler, or storage of power. It makes the explosive mixture, as it needs it, and takes the power from each charge of fuel, as it burns. It has no reserve and no means of multiplying itself, except by increasing the speed. Each charge gives a certain amount of power, and, consequently, the slower the engine the fewer the number of charges, with the result that the power decreases with the speed. At the higher speeds the gas engine is unable to get full charges, or full breaths, and so loses power. It is, therefore, most powerful about midway its range of speed, and decreases each way therefrom. On this account, it is provided with change gears (transmissions), so that it may run at its most powerful speed, while propelling the vehicle either slowly or rapidly, and is only directly connected with the propelling wheels at the highest speed, when it is able to do the work without the use of the gearing. But, even with this limitation, it has advantages over all other motors. When wanted, it will start by turning a crank once or twice over: no fire to start, no battery to charge. While running, it only needs fuel, purchasable anywhere, and quickly supplied, and oil. When stopped, it becomes at once inert, and free from expense or need of care. In this respect, it is ideal. A turn of the crank wakes it into its full titanie power; a twist of the wrist chokes it to death. It is motor, boiler and battery combined. Complex, though it may seem, it requires less space, and weighs less, than the other two varieties of engine, for a given service, and is, therefore, better adapted for automobile use. Younger than either steam or electricity, it has already been simplified and improved ahead of them, and evidences further improvement, and adaptation to the service of the motor vehicle user.

CHAPTER V.

THE GAS ENGINE.

The Theory of the Gas Engine.—While one of the newer prime movers, the gas engine is not of late invention. The inventor of gunpowder placed at the service of mankind a device employing the motive force of the gas engine, and following his invention the suggestion of gunpowder engines soon came. Thus it will be seen that the thought of motors deriving their power direct from the combustion of suitable fuel is almost as old as the steam engine. The gas engine, however, was not properly developed until gas became more or less common, just as many another invention has lain dormant until other things essential to its use or to its creation had been developed. A number of inventors worked on the problem, some of them as early as 1845, and succeeded in getting quite close to the practical device.

The Lenoir Engine and Cycle.—The modern gas engine, however, can trace its ancestry more or less directly back to about 1860, when Étienne Lenoir, a Frenchman, built both stationary and automobile gas engines of the 2-cycle type, which, particularly in the stationary form, found some use in the machine shops of the time. The Lenoir engine, like some of the small toy engines of today, was a non-compression engine, drawing in its charge on the first two-fifths of the stroke, followed by ignition, with resultant expansion, and the accomplishment of work during the remainder of the down stroke; after which the exhaust valve opened, and permitted the burnt charge to be pushed out. The fly-wheel continued the engine in motion during the exhaust stroke, and during the suction part of the return, or downward, stroke. These engines were not economical and were not largely used. They were necessarily quite large, with much friction but little power. They were ignited by a jump spark apparatus, using a Rhumkorff coil.

The Earliest Otto Engine.—The next step worthy of consideration was made by Otto, a German, who exploded a charge of air and gas in a vertical cylinder open at its upper end, this cylinder being provided with a piston, which, by the force of the explosion, was driven freely upward, and out of the top of the cylinder, thus permitting the gases to escape into the atmosphere. On the return stroke, the weight of the piston served to turn a shaft, the piston rod being supplied with rack teeth and pinion with ratchet, working on the down-stroke, but free on the up-stroke, forming the mechanism. This down-stroke being retarded by the work to be done permitted the gases remaining in the cylinder to cool off more rapidly than the piston descent could utilize the space, so a new charge of mixed air and gas was drawn in during the piston descent. The piston was cushioned on this charge of gas and air at the bottom, driving some of it out through the ignition opening, and causing an outside flame to be transferred through this small opening to the charge in the interior, which, exploding, repeated the performance. These engines were somewhat noisy, not being muffled, and because of the suddenness of their actions were not adapted to light foundations nor unstable locations. They were the first compression gas engines to be marketed in any appreciable number; being brought before the public about 1866, and were the predecessors of the now familiar 4-cycle or Otto type of engine.

The Brayton Engine and Cycle.—The Lenoir and the Otto engines were both of European origin, but America was not behind. Without mentioning an early patent of about 1845, which described a fairly practicable air-cooled gas engine, we have the work of George W. Brayton, who developed the Brayton cycle, an engine of the two-stroke type, operating much as a steam engine. In this engine air and liquid fuel were admitted into the cylinder of the engine, burning as they entered. This liquid fuel, being constantly present, and entering as did the air, in varied amount, rather than intermittently, continued to burn between impulses, so that on the opening of the inlet valve, a large burst of flame would fill the working cylinder, and drive the piston before it to the end of its stroke. At this point the exhaust valve would open and permit the diminished flow of air and fuel to escape. On the closing of the exhaust valve at the end of the exhaust stroke, the inlet valve would open; again admitting a large charge of air and fuel, which, because of the flame carried over from the last action, would burn rapidly and repeat the performance. To provide for the admission of air and fuel, the engine operated a pump, which pumped air into a storage tank and also pumped liquid fuel as needed. It will thus be seen that the air tank served as a boiler, but that the flame, instead of being applied to the tank, to expand the air, as commonly applied to a steam boiler, was mixed with and applied to, or, in other words, by combustion com-

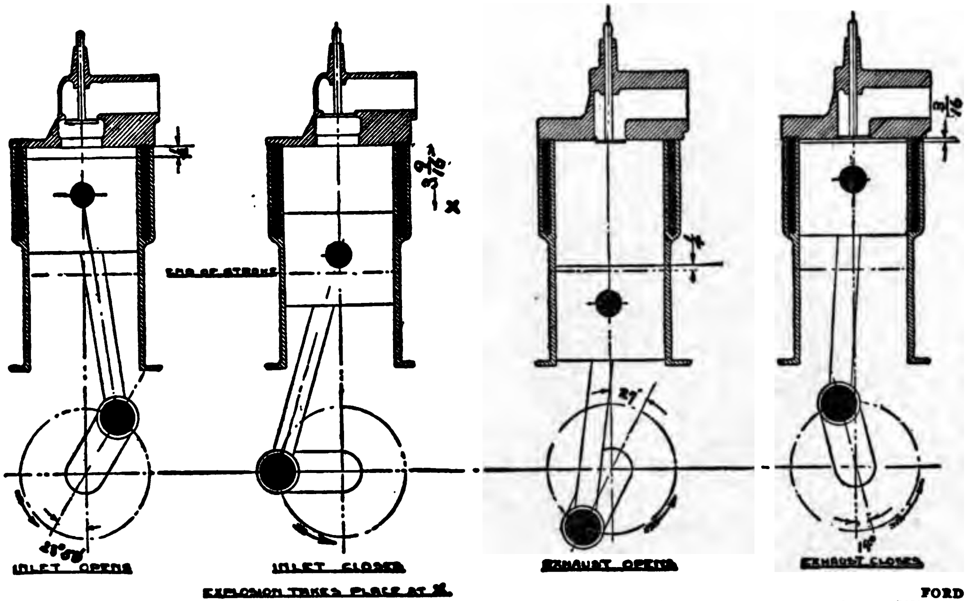


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Fig. 5a.—Sectional diagram of an experimental Lenoir cycle engine, showing operation. With a stroke of 7 inches, the inlet valve opens at 1/2 inch piston stroke, 23° 50' before head center, closes at 3 9/16 inches stroke, 90° after head center, at which point ignition occurs, without compression. Exhaust opens at 1/4 inch before end of down stroke, 27° before crank center, and closes at 3/16 inch on next down stroke, or 14° after head center.

bined with, the small portion of air used at each individual impulse.

Use of the Brayton Engine.—The Brayton engine was a distinct step forward as a prime mover, and found a considerable sale, which was continued on the American market, and, to some extent, on the English market, until about 1885 or 1887, or even later. While not so early as the Lenoir, they were really the first practical gas or liquid-fuel engines in the world, and are entitled to recognition as such. Not only were they used for stationary service, but were applied to boats; to an experimental street car at Providence, R. I.; to a passenger omnibus at Pittsburgh, Pa., and to other more or less interesting uses, such as the pumping of water in the aquarium at the Centennial Exposition of 1876. The Brayton engine, although somewhat more complicated than the Lenoir or Otto, worked on a more economical cycle and ran nearly as smoothly as a steam engine. It could use almost any kind of liquid or gaseous fuel, which was a distinct advantage at that time, when kerosene was still more or less plentiful. While quite simple in operation, it required a working cylinder and a pumping cylinder, which involved a considerable power loss, because of the friction of the pump parts. These engines are probably best known to modern automobile students because of the famous Selden patent, which showed an engine of this type.

The Modern Otto Engine.—Otto did not rest content with his first designs, but about 1876, or possibly a little earlier, brought out the Otto "silent engine," operating upon the Beau de Rochas cycle, a system of gas engine operation devised by a French scientist of this name in the early sixties. In this "silent engine," he used, like the present 4-cycle engines, four strokes of the piston to complete the four stages forming the cycle: viz., (1) a suction stroke to fill the cylinder with fresh mixture; (2) a compression stroke to bring this mixture into compact form in the head of the cylinder, with the piston in position to be driven outward by the explosion, and exert a power effort; (3) the working stroke following ignition, which occurs at or about the beginning of this working stroke; (4) the exhaust stroke, intended to empty the cylinder of the burnt charge. Since the compressed charge requires room in which to be held prior to its combustion, it is evident that the cylinder of a 4-cycle engine must be of greater length than the piston sweep, leaving at the head end a clearance, or combustion space. It is also evident that, on the exhaust stroke, this combustion space cannot be emptied of the burned gases, without employing some means other than the movement of the piston.

Merits of the Several Types.—This short description of the several types of gas engine doubtless makes plain their action, and illustrates how power is obtained from the burn-

ing and expansion of a proper mixture of air and fuel in the cylinder of an engine. While, theoretically, there is very little, if any, difference between the Brayton cycle and the Rochas or Otto cycle, there is in practice a very considerable difference. Otto used but a single cylinder, with few parts and slight cost, where Brayton required a pumping cylinder, as well as a working cylinder, each with a piston, in addition to a storage tank for the compressed air. Brayton could not well avoid loss of heat, arising from the compression of the air, particularly since this air was not used immediately after compression, but was stored for a greater or less period in the compressed air tank. This loss Otto avoided by igniting his working charge immediately at the end of the compression stroke, when the heat of compression was still in the charge, and had not been wasted, or allowed to escape through the walls of the cylinder.

Advantages of the Otto Engine.—This type of engine, therefore, gains value from the double use of the cylinder, and from the fact that the heat of compression passing into the walls, during the compression stroke, is almost, if not

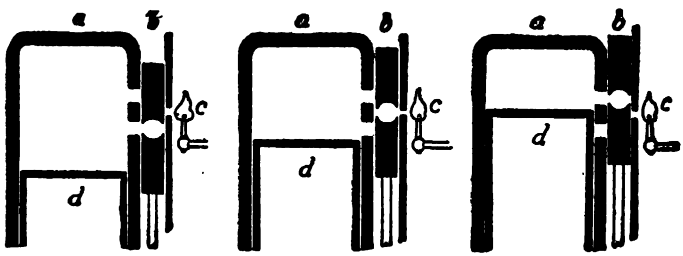


Fig. 5b.—Diagram of the cycle of the Otto slide ignition, showing *a*, cylinder, *b*, slide with pocket, *c*, gas flame, *d*, piston.

wholly, restored by the immediate sequence of the working stroke, which permits this heat to expend itself in expanding the working gases. Like the Brayton, the Otto engine required valve actions, but, unlike it, required an ignition system to operate at the close of each compression stroke.

Early Ignition Methods.—While in the original Otto ignition was effected by an outside flame through a small hole in the cylinder wall, in the later or " silent " Otto this method was modified by providing a slide, having this hole, but protecting the engine against loss of compression. Ignition was effected by sliding this ignition aperture slightly at each ignition period, so that the hole or pocket in the slide, (1) filled with fresh gas, by being placed in front of an opening into the cylinder; (2) moved behind an opening through the outer engine wall to an open flame, and (3) moved to the

opening into the cylinder, which permitted the flame then burning in the pocket—it had been ignited through the hole from the outside flame—to communicate itself to the charge inside the cylinder of the engine. It may thus be seen that, by this sliding-pocket arrangement, a flame was carried, at each ignition period, from outside the cylinder, to the new charge inside, with reasonable certainty of successful ignition. This sliding valve was large, was held on its seat by heavy springs, and offered considerable friction, when the slight power required to perform this ignition function is considered. While used by a number of other engines, as for example the Nash in America, it was soon superseded by hot tube as an ignition device.

Ignition by Hot Tube.—This use of the slide in gas engines was first found in the Lenoir, which employed slide valves, much like the steam engine, instead of poppet valves, as used in most later gas engines. The slide ignition was not used in automobile practice, owing to the fact that modern automobiles did not come before the public in quantity, until the slide had passed away before the more simple, certain and successful hot-tube ignition. This latter method of ignition employed a small tube of platinum, porcelain, or even iron or copper, open at the end, which end was screwed into a hole in the cylinder wall, the outer, or closed, end being heated by a torch or Bunsen flame to a red heat. When the compression stroke of the piston compressed the gas into the head of the cylinder, a small portion of the new charge was driven into the open end of this hot tube and, reaching the heated portion, became ignited, and carried the flame to the remainder of the charge. Hot-tube ignition was employed on several foreign automobile and boat engines, as late as the first years of the present century. The uncertainty of porcelain, the rapid burning-out of iron, and the high cost of platinum, all militated against the continuation of this certain, although not well-adapted, method of ignition for automobile engines. The great fault of the hot-tube system was its lack of flexibility, it being evident that the new charge would not reach the hot portion of the ignition tube until the compression had attained a pre-determined pressure. Thus the speed of the engine could not be successfully varied, because, at high speeds, the gas would not reach the ignition point in the tube and convey the flame outward quickly enough, although, at low speeds, the opposite trouble was encountered in more or less premature ignition and consequent negative work.

Throttling a Gas Engine.—Since compression was recognized as one of the essential features of the economical and successful gas engine, it was believed that the throttled engine could not be satisfactory. This theory-born belief, coupled with the inflexibility of the hot-tube ignition, greatly

retarded the proper development of the automobile in Europe. A different practice was established in America, when Charles E. Duryea began experiments with automobile motors in 1891. After vainly trying to purchase Daimler, or other engines, suitable for his motor-vehicle experiments, he began building for himself, following such information and precedents, as could be obtained. He first constructed engines of the hit-or-miss type, that is to say, engines of the Rochas cycle, which took a full charge, or no charge, as required, in order that they might be economical and be certain to ignite. At that time in America, however, electric ignition by the make-and-break spark was not uncommon in stationary engines, and this, instead of the hot tube, was utilized by Duryea, as affording some variability of the time of ignition, which could not be so accurately fixed with the hot tube, nor so easily varied. His use of the engines built by himself, on his vehicles soon showed the advantage of throttling, with the result that, in 1894 or 1895, a two-cylinder engine was built, having means for cutting out the governor, and thus permitting the operator to control the engine, by removing the governors, and depending entirely upon throttle control. This throttle control consisted, as in a steam engine, in admitting a greater or smaller mixed charge of air and fuel, as more or less power was required of the engine, and demonstrated a wide range of flexibility, previously largely unattainable in a gas engine.

Early 2-Cycle Engines.—About this time, or for some years previous, Dugald Clerk, an English authority on the gas engine, had conducted experiments on the two-stroke cycle, as also had Day, Nash, Sintz, and some others. The 2-cycle engine, in the early 90's, as at present, seemed attractive for automobile work, and received more or less attention, but, being less developed than the 4-cycle, it seemed the part of wisdom to employ the better-known form, then much more practical.

Theory of the 2-Cycle Engine.—The 2-cycle engine employs the same cycle of operations as does the 4-cycle, viz., suction, compression, working, exhaust, but unlike the four-stroke cycle, which devotes a stroke of the piston to each of these operations, it utilizes one side of the piston head for two of these purposes, while the other side is being used for the other two. Thus the suction and compression strokes take place at the same time, the suction of the piston on its up stroke drawing a new charge into the crank case, while this same up stroke is compressing the previous charge into the cylinder head. On the down or working stroke, the gases in the cylinder head having been ignited, the under side of the piston compresses the new charge lightly in the crank case, and thus stores in it sufficient energy to exhaust the old charge when the proper ports are opened. It will thus be seen that, as the Otto engine was superior to the Brayton,

at it used one cylinder instead of two, the 2-cycle engine perior to the 4-cycle, because it uses two piston strokes erform its four operative functions, instead of four :es, as does the older and more familiar 4-cycle form. 4-cycle engine is still more in evidence than the 2-cycle, ıse it was first developed, and, being more perfected and r known, was given preference by builders of automo- , who felt that they had a sufficient number of problems ·e them for solution, without attacking this newer and developed type of engine. Happily, this condition of ·s does not exist today, for in the past decade the 2-cycle ıe has greatly improved in flexibility, lightness, power, licity and reliability.

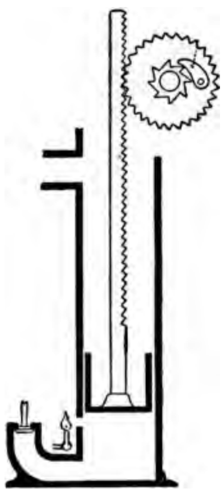


Fig. 5c.—Sectional diagram of the first Otto gas engine.

CHAPTER VI.

THE CYCLES OF GAS ENGINES.

The Four-Cycle Gas Engine.—Progress is from the complex to the simple, because the inventor, seeking a desired result, gropes about till he has combined mechanism enough to accomplish the desired end. Later, he finds it possible to accomplish the same result with simpler and better devices, and does so. The 4-cycle engine is an example of this procedure. It is the first gas engine to be largely adopted, and quite fully worked into its best form. But it is also more complex than some other less common forms, such as the 2-cycle. It consists of one or more cylinders, each having a piston, connecting rod, crank, and suitable framing or casing, with inlet and exhaust valves, and mechanism for operating them. In practically all automobile gas engines the piston is of the "trunk" type, open at one end and carrying a pin forming the connection for the connecting rod. It serves the combined function of piston and crosshead, as used in most steam engines. This construction is used because of the heat of the explosive charges, which make a double-acting cylinder and piston hard to cool and add to the difficulties more than the gain in power would amount to. In automobile engines the Beau de Rochas cycle has long been employed. In this each charge of gas or vapor of gasolene and air is (1) sucked in, (2) compressed, (3) fired at the point of highest compression, or thereabouts, and then (4) exhausted. Not counting the firing (ignition), these four actions require four piston strokes to accomplish the cycle; viz., (1) a downward or suction stroke, (2) an upward compression stroke, (3) a downward working stroke and (4) an upward exhaust stroke. This completes the cycle, which the next four strokes merely repeat. Because of this method of operation it is called a "four-stroke-cycle," or, briefly, "four-cycle."

The Inlet Stroke.—To be more specific, the suction stroke of the piston draws the new charge of explosive mixture

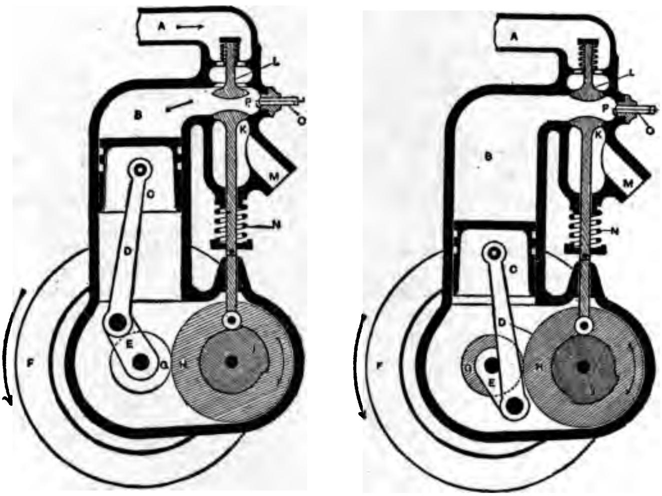
through an inlet valve. Formerly, this was always suction operated, but is now opened mechanically. It may be in the head of the cylinder, or in a pocket at the side of the cylinder, or even in the head of the piston, as in some æronautic engines. This valve opens at about the time the piston starts downward, or shortly thereafter, and remains open to the full end of the stroke, or a little after.

The Compression and Firing Strokes.—Next the piston starts upward, compressing the charge with both valves shut. At, or near, the top the ignition takes place, which greatly heats and expands the compressed charge; but, since the space has only a given cubic content, the heating produces a high pressure, and this drives the piston downward with great force. The main object of the compression is to get the piston into position to do work. If it was already at the end of its stroke it could not move further; if part way down, the first part of the stroke would be lost; but, by having the piston at the beginning of the working stroke, it can deliver power through the whole length of the stroke.

Advantages of Compression.—Another object is to get a large amount of power out of a small engine. If the compression space was simply filled with gas under no pressure other than atmospheric, it would contain but one-third to one-fifth as much as it contains when compressed in the usual method. Therefore, there could be but one-third or one-fifth the power, which is obtained by getting a much larger amount of gas into this small space by compression. To state it differently: if atmospheric pressure only is used before ignition, and the expansion of the gas, due to ignition, raises the pressure four times, the working pressure would be, roughly, 60 lbs. But, by compressing the charge to 50 lbs., before ignition, the working pressure becomes 200 lbs. This enormous difference is greatly in favor of compressing highly, and the economy of the engine increases with high compression till the pressures are limited by conditions which will be explained elsewhere.

The Exhaust Valve.—Near the bottom of the stroke the exhaust valve opens and lets out the exhausted gases, after they have largely expended their pressure. In very slow engines it suffices to open the exhaust at crank dead center, but, if speed is desired, this is not soon enough. The useless gas must get out of the way of the returning piston, and so the exhaust opens from 20° to 45° ahead of dead center, or even earlier. This involves some loss of power near the end of the stroke, but the crank is not then at a favorable angle for work, nor is the pressure of the gas high at the end of the stroke. It is easily found by experiment that the high-speed, desired in high-powered engines, requires this early opening. The exhaust valve also opens against the pressure, and so must be lifted mechanically. It, therefore, requires

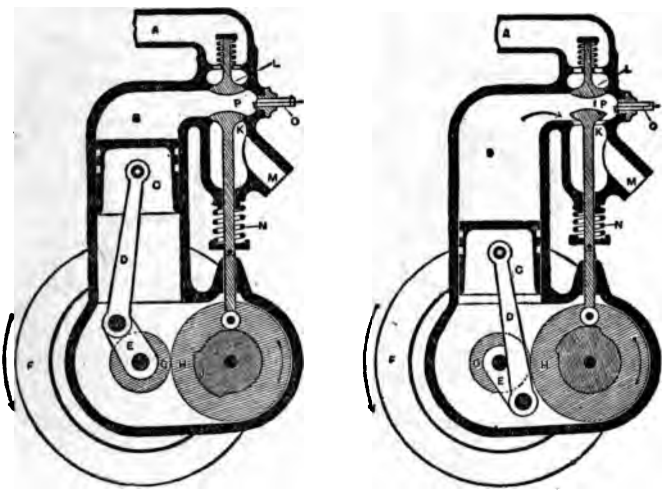
some sort of valve lifter; and, since it is opened but once in four strokes of the piston, corresponding to two revolutions of the crank-shaft, this valve-lifter is usually operated by a half-time shaft, driven by a set of gears. The smaller of these is on the crank shaft, and the larger one, twice the size of its mate, is on the valve-lifting shaft, often called the cam shaft. In engines having the inlet valve mechanically operated a second cam and valve lifter is used. Often, also, a second set of gears and a second shaft is provided.



Figs. 6a. and 6b.—The cycle of a four-cycle gas engine; 1 at the beginning of the inlet stroke; 2 at the beginning of the compression stroke. A, inlet, B, combustion chamber, C, piston, D, pitman, E, crank, F, fly-wheel, G, main shaft gear, H, cam shaft gear.

The Exhaust Stroke.—On the next up-stroke of the piston the exhaust valve remains open, and allows the piston to push the remaining burned gases out of the cylinder. At the top of the stroke the exhaust valve closes, and, shortly thereafter, the inlet opens, and the next cycle of operations begins. Generally, there is some lag allowed to the valves, so that they do not open and close so early as indicated, especially if speed is desired, but the amount of lag is also dependent on the size of the valves and their quickness of operation. The crank is usually enclosed in a tight case, so as to both keep out the dirt and keep in the oil. To avoid pressure within the case it is common to fit a vent pipe, or breather, so that any gas escaping past the piston may escape; but this is not necessary.

Auxiliary Exhaust Ports.—In some engines, particularly if air-cooled, ports are provided in the cylinder wall just above the top of the piston, when it is at the bottom of its stroke. Such auxiliary ports let out the main pressure, and avoid sending the full amount of hot gas out through the exhaust valve, with danger of heating, warping and burning the valve. The value of such ports is well recognized, but in water-cooled engines they are considered an unnecessary expense, since the main exhaust valve must be present, and, if



Figs. 6c. and 6d.—The cycle of a four-cycle gas engine. 3, the beginning of the working stroke; 4, the beginning of the exhaust stroke. J, exhaust cam, K, exhaust valve, L, inlet valve, M, exhaust pipe, N, valve spring, O, spark plug, P, spark chamber.

kept cool by water, is fairly safe from burning. The action above described is that of a single cylinder engine, but all additional cylinders act similarly.

The Two-Cycle Gas Engine.—In this type of engine the same working cycle is employed, but it is completed in two piston strokes, instead of four. An upward movement of the piston draws the charge of mixture into the crank-case, just as any pump plunger pulls in its charge, or as the piston of the 4-cycle fills its own cylinder. But, during the same stroke, the head of the piston compresses the previous charge in the cylinder, followed by ignition, just as in the 4-cycle engine. The piston moves downward under the expansive force of the burning gas, in the same manner, as just described, and does its work. At the same time, the down-

stroke compresses the new charge in the crank-case, for the purpose of driving it from the crank-case, and into the cylinder. When near the bottom of the stroke, the piston uncovers the ports in the cylinder wall, thus letting out the burnt gas, which, by its escape and expansion, loses its pressure and heat, much as in the 4-cycle engine. At this time the new charge, compressed in the crank-case, passes through a passage (the "by-pass") provided around, or through, the piston into the cylinder, and is thrown, or deflected, so as to pass to the head of the cylinder and crowd out the old gas. It thus completes the exhaust action, while the piston is still near the bottom of the stroke, and the exhaust ports are still open. This completes the cycle, and the next upward stroke of the piston again pumps and compresses as before.

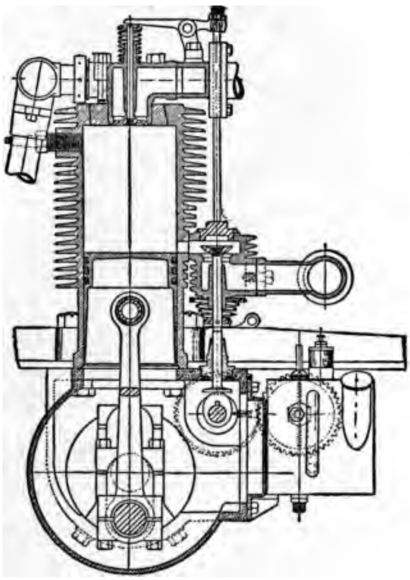


Fig. 6e—Section of a model of the Franklin engine, showing the auxiliary exhaust port and valve at the bottom of the piston sweep.

Advantages of the Two-Cycle Engine.—By doing two parts of the cycle on one side of the piston, and the other two parts on the other side, the engine is made to work under power on every down-stroke, instead of on alternate downstrokes. More power, therefore, is obtained from a given size of cylinder. The mechanism is also simpler, although the action is doubly complex; for, since two actions are being performed at one time, it is harder for the novice to understand just what is transpiring. This explains why the

2-cycle engine was not developed till after the 4-cycle, and makes clear also that, being simpler, it needs only to be understood in order to be preferred to the older type.

Two-Cycle Troubles.—The 4-cycle engine is so well known, and each part can be so readily seen performing its function, that there is little need to dwell on its hidden possibilities of trouble. But the 2-cycle engine has some traits that should be known and must be considered. The 4-cycle engine varies but little. One design is practically like another. The valves may be differently located or operated by different means, but they are still valves, and perform the same functions. It is not possible to leave out the exhaust valve, even if a port is provided, in the cylinder wall, and the inlet valve must be present, somewhere or somehow. Sliding sleeves may be used for valves, as in the much-

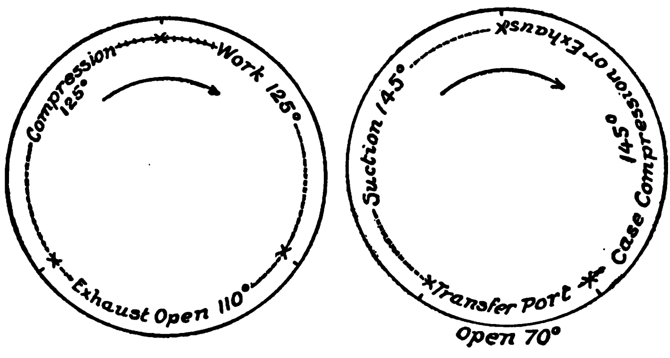


Fig. 6f—Diagram of the cycle of a 2-cycle engine, showing succession of operations occurring in the cylinder and crank-case, with degrees of arc, indicating the portions of the revolution in which each takes place.

exploited Knight, or pistons may be used, as in an early Knox engine, and some more recent types, or a rotary valve, as shown, notably, in the Duryea, Darracq, and others, but, in all cases, the valve action is there, and the service performed by the chosen device varies but little from a given type. On this account the user needs to look for but few causes of trouble. If (a) the carburetor is delivering explosive mixture; if (b) the cylinder and its piston hold compression; if (c) the valves are tight; and if (d) the spark occurs at the proper time, the engine will surely run, if not held from turning by some potent interference. In general, the search for trouble is confined to the cylinder, and its immediate connections. But, in the 2-cycle engine, the hunt for trouble must also include the crank-case.

Varieties of Two-Cycle Engine: The "Three-port."—There are three, or more, kinds of 2-cycle engine, all of which differ and present a slightly modified problem. The best known, and most used, type of boat and automobile 2-cycle is the "three-port" form. Instead of having an inlet valve to admit the mixture to the crank case, there is simply a port placed in the cylinder wall below the exhaust, but where it will be uncovered by the piston at the top of its movement. As the piston moves upward, it makes a partial vacuum in the crank case, which lasts till the port is opened, and then a rush of mixture from the carburetor fills the case, before the piston can start downward, and close the port. This port usually remains open through about 90°, and its advantage lies in the fact that the passage into the case is free from valves which restrict the admission of a full charge of mixture. It is the simplest form possible, since it omits the valve.

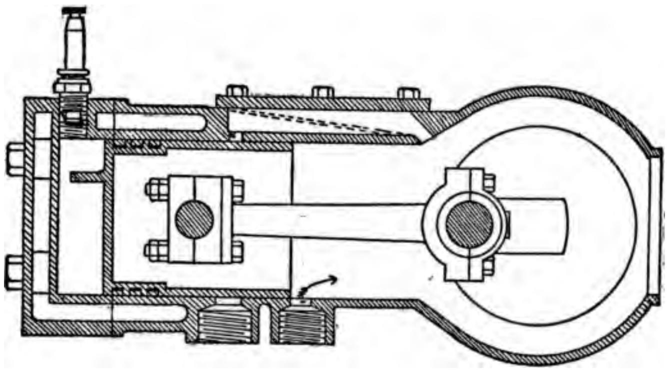


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Fig. 6g.—Section through cylinder of a three-port 2-cycle engine, showing intake to the crank-case at head centre, the piston opening the inlet port.

"Three-port" Engine Disadvantages.—The "three-port" engine has disadvantages. Thus, during the upstroke, the partial vacuum may fill from the outside air through any opening that may happen to be in the case. The crank bearings offer one place where air may get in, although, to their credit be it said, they are not so often guilty as supposed. They are usually quite long, and well oiled with cool thick oil, and fit so closely that they do not pound in operation. The exhaust port is a frequent source of admission, and the admitted material is not pure air, which would mix with fuel and add to the combustion, but is exhausted gas which cannot be burned again. The piston can not be really tight, since it must move in the cylinder rapidly; and a very tight piston

would add much friction, or even stick and stop the engine. This will be more fully explained later. Any leaks about the crank-case are also possible causes of admission of air.

Varieties of Two-Cycle Engine: The Valved Crank-Case.—To avoid this vacuum in the crank-case, with possibility of leaks into it, many 2-cycle engines are made having an inlet valve. This is most commonly of the poppet or check form, but sometimes is a disk, rotating with the shaft, and uncovering an inlet opening at the proper part of the revolution. The disk type will not admit mixture, if the engine starts backward, but this is of little advantage, and is sometimes a disadvantage, for it is occasionally desirable to reverse the engine. This type of 2-cycle draws in its charge during a whole piston stroke, just as does a 4-cycle engine, and, with steadier action. It starts easier, and is believed

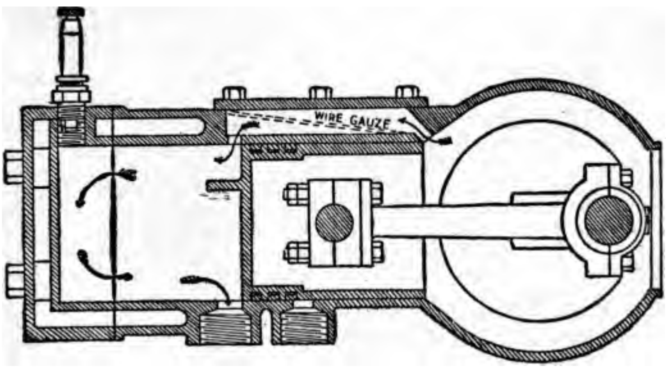

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Fig. 6h.—Section through cylinder of a three-port, 2-cycle engine, showing exhaust and transfer to the cylinder at crank center.

to deliver more than double the power at slow speeds. The added complication, consisting of a single light valve, is of no importance, because the valve is not exposed to heat, and can be made very light, having only low pressures to deal with.

Two-Cycle Ports and Their Troubles.—Most 2-cycle engines carry the mixture from the crank-case to the cylinder through a transfer passage placed close along the cylinder side. This enters the cylinder opposite to the exhaust ports. In slow-speed engines, as for boat use, these ports do not extend far around the cylinder wall, and, therefore, have considerable width of wall between their ends. This acts as a packing surface to prevent passage of gas around the piston between the rings, and parallel to the rings. But, in the

high-speed engine, the ports are made as wide as possible, and this brings their ends close together with certainty of leak around the piston, depending more or less on the tightness with which the piston fits the cylinder. It will be apparent, therefore, that the compressed mixture may escape from the crank-case passage around the piston, into the exhaust, or that the exhaust may be drawn into the crank-case in a reverse direction.

The Piston-Head Deflector.—The entrance to the cylinder being at one side of the cylinder, and the exhaust at the other, it is quite evident that a deflector must be provided on the piston head, to turn the incoming gas up to the head of the cylinder. On the shape of this deflector much depends, for, if the new charge is not sharply turned upward, and thus kept separate from the old, it mixes badly, and much of it passes out the exhaust with the old. This mixing tends to heat the new charge, and may ignite it, with a resultant rush of flame back into the crank-case, which remains so filled with the hot burned gas that the next charge or two will not fire, when admitted to the cylinder.

The By-Pass and Screen.—To prevent backfiring, from this or other causes, it is customary to place a woven wire screen across the transfer passage. Copper wire is usually used for this, and, occasionally, brass, but the brass wire is bad, because easily fused by a rush of flaming gases. The preferred arrangement seems to be to use a steel screen of about 30-gage wire, 30 meshes to the inch, and place this under or over a plate of perforated steel, having fully half its surface cut by perforations of 5/16 or 3/8 diameter. The gas goes through the perforations, and heats the wire at each small spot, but the wire under the solid metal keeps cool, and quickly draws the heat out of the hot areas, leaving them cool for the next charge. If not so protected, the screen may get hot throughout, and may fire the gas on the other side by its own heat, even though not allowing the flame to pass through it; thus acting as if it offered no protection. The sheet metal also stiffens the screen, and prevents vibrations from breaking it.

The Valved Piston.—To prevent the leaks from one port to the other, and lessen the mixing of the old and new charges, some 2-cycle engines are built with a valve in the piston head, and a conic deflector on the piston, to throw the entering gas up to the center and top of the cylinder. This, while having the added valve, secures a practically straight flow of gas, which emerges from the cone in a solid round stream, and passes, with the least possible surface exposure and mixture, up through the old charge, massing in the cylinder head, and crowding the old charge down and out. The lessened mixing of this round stream of new charge with the old, as compared with the mixing of a more or less flattened

stream, admitted from the side and thrown into eddies by the deflector, is a matter of considerable economy. Further, the tendency of the side-admitted charge, if carefully deflected up one wall, to avoid mixing, is to follow over the top and down the other side, passing out with the exhaust. Compared with it, the central admission, massing the new gas in the head, secures both economy and power. The crank-case compression 2-cycle engine is admitted to be the simplest general form, and the valve-inlet, valved-piston form seems to be the best for automobile use.

Valved Piston Advantages.—In the valved-piston engine the exhaust ports can be let into the wall all around the cylinder, and, being thus more than twice as wide as in the side-transfer-passage type, they will do their work in half the time. Therefore, they need not open till about 35° to 40° ahead of dead center, with consequent gain in power and lessened noise. When the pressure gets low enough to

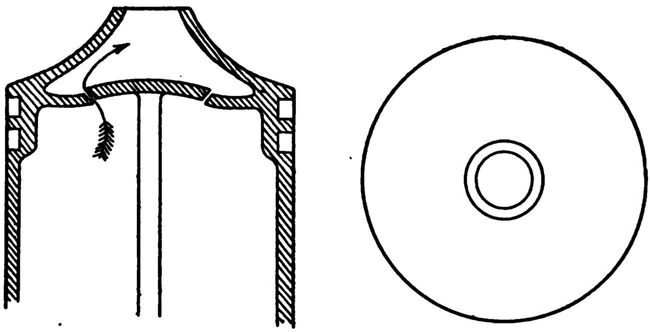


Fig. 6j.—Section and top view of a valved piston for a 2-cycle engine, showing device for throwing the incoming gas to the top of the cylinder space.

permit the valve opening, it does so, and the valve can remain open, till the pressures in the crank-case, and in the cylinder, balance, even if the exhaust ports have closed. It thus allows practically the same time for admission as the port transfer type, but, since the admission is later, the flame of the preceding charge has more time to extinguish. The fact that the valve opens by pressure of the gas insures a rapid speed through the port at all times, and this practically insures prevention of backfiring, although the screen can be provided in the piston.

Engines with Charging Cylinders.—While the above descriptions cover the more common form of automobile engines, there have been some attempts to make engines of the 2-cycle type having one working cylinder, in which

the impulses occur, and one charging cylinder, instead of a crank-case. Such a construction, although having two cylinders, should not be confounded with a proper two-cylinder engine.

Differential-Piston 2-Cycle Engines.—There are many modifications of the 2-cycle engine, but most of them have not become recognized in the automobile business. One of the more common forms employs what is called the "differential piston." This is a piston having two diameters, the smaller-diameter portion being made longer than the stroke, so that it is never out of its cylinder, when drawn

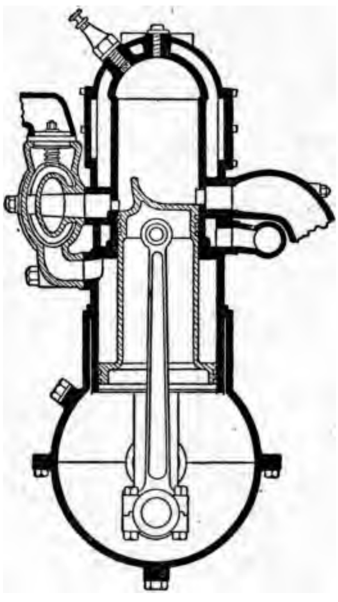


Fig. 6k.—Sectional diagram of a "differential" or two-diameter piston engine, showing annular chamber into which fuel is drawn, instead of into the crank case, also the special by-pass valve for inducting the compressed charge into the cylinder.

down into the larger cylinder, which is closed by the enlarged open end of the piston. The leading reason for using this type of piston is to avoid compression in the crank-case. The new charge is drawn into the annular cylinder with the larger piston, on the down stroke, while the ignited and expanding charge is doing its work, instead of being drawn in on the upward or compression, stroke as in the usual 2-cycle. On the upward stroke, the charge next

to be ignited is, of course, compressed in the working cylinder, while the charge drawn into the annular cylinder is also compressed, more or less, and is forced, either into a reservoir or into the next cylinder, there to be ignited. The latter arrangement is more common in this type of engine, and, by using two cylinders, it takes the place of crank-case compression, and secures fairly complete transfer of the charges. It is quite evident that there must be some passage length and volume between the annular compressing cylinder and the adjoining working cylinder, which shall serve as a clearance space, and permit the gas to be compressed therein. Because of this space the enlarged end of the piston can travel up the full length of the cylinder, and thus needs no clearance worth mentioning at that place. In an automobile engine of some prominence, three cylinders have been used, employing this differential piston, but instead of piping directly to the next piston a form of distributor valve has been used to send the working charges to the proper cylinder.

Two-Cycle Engine Timing.—Before leaving the 2-cycle engine, attention should be called to two considerations of importance. It is quite common to open the exhaust port nearly 60° of crank movement prior to the lower dead center, whereas the exhaust of the 4-cycle is opened about 45° prior. This results in some loss of power, due to the fact that the gas has not completed its working capacity, but this opening is considered necessary, in order to get the old charge out of the way of the new one, which is usually admitted at 40° to 45° prior to the end of stroke.

Cylinder Cooling.—The other thought relates to cooling. The heat of the burning charge heats the inner surface of the wall, and this heat is carried by the iron at a very slow rate toward the outer wall, where it must be carried away by the cooling means. How slow this rate is may be roughly estimated by cooling one end of a hot bar, and watching the travel of the color, due to the heat, along its brightened surface, as is done in tempering tools. In the 4-cycle engine the hot gases remain in contact with the wall, with more or less heat in them, for 360°, or a complete revolution, during which time the heat passes quite deeply into the wall; since, as is evident, the greatest heat is just after the ignition. In the 2-cycle, the opening of the port, at 60° to 35° prior to the bottom of the stroke, stops the heating at 120° to 145°, and lets in the cool charge at once, and before the heat has had time to enter the wall so deeply. It is, therefore, practically certain that a smaller proportion of the heat goes through the wall, and that a greater proportion is absorbed by the new charge. This practice of holding the heat only ⅓ so long, and better cooling, due to the new charge, renders the 2-cycle engine easier to cool than the 4-cycle, in spite of the double number of ignitions. The greater heating of the new

charge by the walls, after entering, also adds economy by insuring more certain ignition, and permitting leaner mixtures to be used. In the valved-piston type the new charge passes through the piston head center, and strikes the cylinder head center; thus helping to cool these two points which are usually the hottest and most difficult to cool.

CHAPTER VII.

GAS ENGINE ELEMENTS.

The Cylinder and Piston.—The operative elements of a gas engine are the cylinder and the piston which works in it. Cylinders are usually employed in pairs—two, four, or six—for several reasons, one of which is that the single cylinder engine at first used in automobile practice, now largely discontinued, resulted in considerable vibration, which was objectionable to the automobile users. This vibration arose from the large size necessary to propel the vehicle, and also from the unbalanced portions of the engine which the single construction involved.

Piston Balancing Devices.—While there were some attempts at balancing these parts—as in the early Wintons, which used a bob weight driven by an eccentric on the crankshaft, or in the later Brush, which employed a sort of second fly wheel geared to the main fly wheel, but revolving in an opposite direction, and properly bob-weighted—the complications added to secure the balance were disadvantageous, and the cost of the extra parts was practically as much as a second cylinder and its parts would have added without the resultant gain in smooth running, added power, and similar advantages.

Two-Cylinder Advantages.—On these accounts the two-cylinder engine has long been a favorite for automobile work, and is still continued by a number of makers. It permits setting the cranks opposite each other so the moving parts and the explosions are both in balance if the engine is of the 4-cycle type, and the cylinders opposed—that is to say, on opposite sides of the crank-shaft—or if the cylinders are side by side, and the engine of the 2-cycle type.

Multiple-Cylinder Engines.—With the growth of the automobile, the increased power and speed demanded, the

heavy weight and the large seating capacity desired, there came a call for greater power, which was first met by increased cylinder sizes in the two-cylinder forms, but later by the use of a larger number of cylinders, such as three cylinders in a few instances like the Duryea, Phelps, Thomas, Gasmobile, and some others. The more common arrangement employed four cylinders, which form has become most common, and probably will remain as the leading type of engine for many years in the future.

Four-Cylinder Constructions.—The four-cylinder engine could be made with separate cylinder castings, or by combining two twin cylinder castings on the same base, a construction quite common with many makers. This twin casting often has the inlet and exhaust passages within the casting itself, thus saving joints and piping, while a more complicated casting than this offers some difficulties which foundrymen and pattern-makers did not seem inclined to work out until later years.

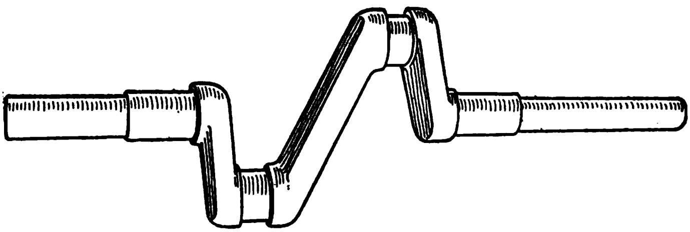


Fig. 7a.—A two-cylinder crank-shaft with throws at 180°. This form of shaft is used on opposed cylinder four-cycle engines, or on parallel (twin) cylinder 2-cycle engines.

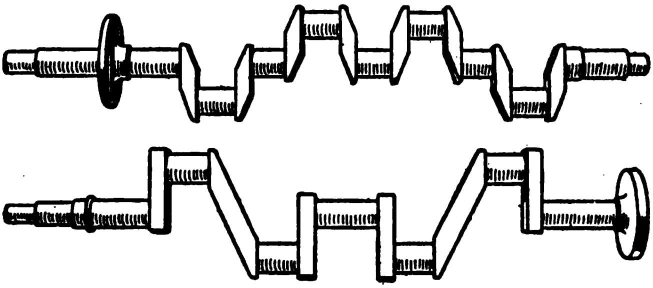
The Four-Cylinder Crank-Shaft.—The four-cylinder engine also permitted the use of a crank-shaft with its throws on opposite sides 180 degrees apart, which shaft could be made from a slab of steel, by machining processes wholly, and without twisting or shaping by heat or forging, as a three-throw shaft required. These several reasons brought the four-cylinder engine into prominence in spite of the fact that the three-cylinder, four-cycle engine is the simplest and most compact multiple cylinder form which can be devised for motor vehicle work.

Three-Cylinder Advantages.—It is believed by many that with three cylinders ample power can be secured for reasonable sized automobiles for passenger use without unduly increasing the size of the cylinders, and thus render it difficult to secure proper cooling, proper lubrication, or proper strength of parts, and that the use of four cylinders or more is an unwarranted complication and extravagance, both on

the part of the maker and the user. Whether this be true or not the fact remains that a great majority of makers produce four-cylinder cars, and made them the leading type.

Six-Cylinder Engines.—With a few exceptions no five-cylinder cars have been produced, possibly because the crank-shaft is rather difficult to produce, and also because the six-cylinder, like the four, can be built up of smaller units of two or three cylinders in a single casting. The former arrangement was the more common, but of late years six cylinders composed of two blocks of three-cylinders each are quite common.

The Six-Cylinder Crank-Shaft.—The six-cylinder crank-shaft is practically a combination of two "threes," one of which is spiralled opposite the other,—that is, one crank-shaft being right hand, and the other left hand, as regards the sequence of the power strokes, which arrangement secures the most even balancing of both the moving parts



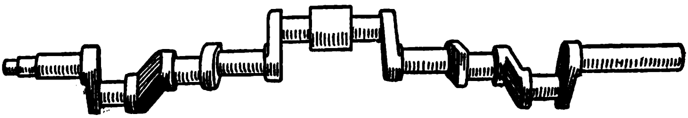
Figs. 7b. and 7c.—Four cylinder crankshafts. 1, a five-bearing shaft; 2, a three-bearing shaft.

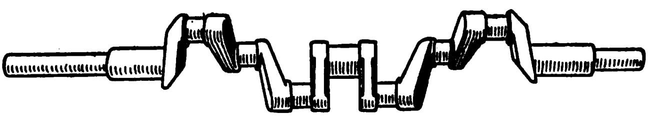
and the explosions. While it is not necessary to have these halves of a six-cylinder crank-shaft spiralled in opposite direction, it is considered the best practice, and this thought, in connection with the three-cylinder engine is probably one of the reasons why it has not been more commonly adopted, namely that the crank-shafts must be made one way, so as to be interchangeable in any given factory, while, as a matter of fact, errors easily crept in, and shafts were frequently spiralled the opposite way, which necessitated a change in the cam-shaft. Whatever the cause may be, the three-cylinder never attained much usage, and the six-cylinder, although apparently growing in favor, has never reached the prominence of the four.

Service or Fashion?—So long as wealthy buyers looking for something ultra rather than for the most serviceable and practical, are to be found, that long will makers cater

by supplying larger, more complicated, more expensive, and more unwarranted constructions, and in this class come the eight-cylinder engines, used on several recent cars. That these were splendid running engines no one denies, but the complication, cost, weight, and similar objections undoubtedly outweighed any gain in the matter of smooth running, small vibration, or other good features.

Engine Vibration.—Some thoughts on the subject of vibration may not be amiss here. It will be readily seen that given two engines of equal power, one being a single-cylinder, and the other double, the vibration arising from the impulse of the double-cylinder will be roughly one-fourth that of the single-cylinder, because the impulses are but half as large, and come twice as often. With the three-cylinder engine, as compared with the single-cylinder of the same power, the impulses are but one-third as strong, and





Figs. 7d. and 7e.—Six cylinder crank-shafts. 1, a four-bearing shaft; 2, a three-bearing shaft.

the time between them one-third as long, so that the three-cylinder vibration is, roughly, one-ninth that of the single-cylinder engine.

Advantages in Decreased Vibration.—It may be readily seen that the difference between one and one-fourth is quite large, but the difference between one-fourth and one-ninth is considerably less, while the difference between one-ninth and one-sixteenth, representing the vibration due to the impulses of the four-cylinder engine, is getting down to the point where it is negligible; while the difference in vibration between the four-cylinder engine and the six is so small that only a practised observer can detect it. In fact, many automobile users are unable to tell by the feeling of the vehicle whether they ride in a car propelled by a four-cylinder or a six-cylinder engine. The principal indication is the frequency of the exhaust, rather than the vibration of the engine, for with proper balancing, and proper placing of the

engine, likewise suitable springs, no serious vibrations reach the user of the car in any well made automobile, and the matter of vibration, as applying to engines of a different number of cylinders, is one of theory, rather than of actual practice.

Increasing the Power Output.—The principal reason for increasing the number of cylinders is not to get a smoother-riding, or more steady-pulling, as many suppose, although there is something gained by a steady application of power instead of by a more broken application, particularly in the strength of the parts, but the gain in power without increasing the size of the cylinder is the principal reason for multiplicity of cylinders. In order that the vehicle may be light weight, and that its parts may be small, compact, not expensive to produce, and able to last long, the designer prefers to keep the cylinders small and the impulses light, and to

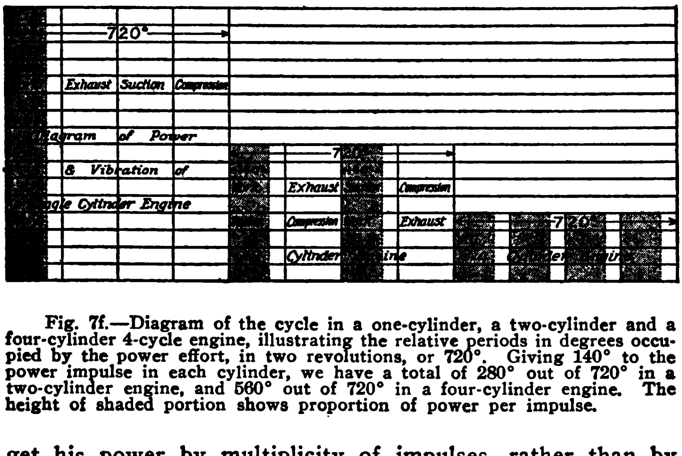


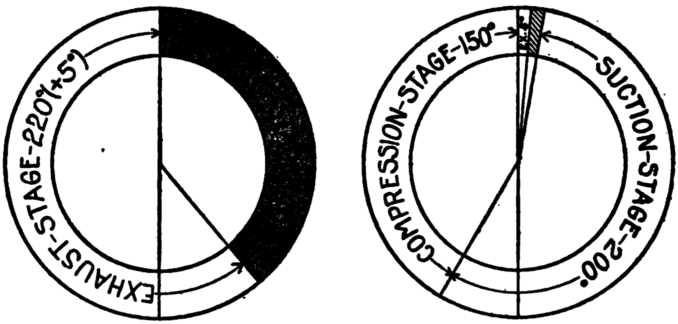
Fig. 7f.—Diagram of the cycle in a one-cylinder, a two-cylinder and a four-cylinder 4-cycle engine, illustrating the relative periods in degrees occupied by the power effort, in two revolutions, or 720°. Giving 140° to the power impulse in each cylinder, we have a total of 280° out of 720° in a two-cylinder engine, and 560° out of 720° in a four-cylinder engine. The height of shaded portion shows proportion of power per impulse.

get his power by multiplicity of impulses, rather than by their magnitude. The small cylinder also is more easily cooled, is cheaply built, and probably can be lighter in proportion to its power than the large cylinder, which is more susceptible to change of shape when heated.

Advantages of the Two-Cycle Engine.—These arguments point strongly toward the 2-cycle engine as being the one most favored for automobile work, since the 2-cycle engine gives double the number of impulses from a given number of cylinders that can be produced by the 4-cycle. Further, the 2-cycle engine, having an opposed crank-shaft, carries its two cylinders side by side, both with mechanical parts and impulses balanced, and like the three-cylinder, 4-cycle it is the most compact multiple-cylinder form of its kind.

In spite of this, most of the 2-cycle engines thus far applied to automobile practice have been of the three- and four-cylinder variety, just as most of the 4-cycle engines have been of the four-cylinder, with a large following of sixes. That this will continue to be the case seems improbable, because of the extreme simplicity of the two-cylinder engine, with consequent low cost, light weight, easy starting, high economy, and many similar features, which, sooner or later must win recognition from the buyer who seeks for service rather than fashion.

Multiple-Cylinder Constructions.—These foregoing remarks concerning the various types of engines as differentiated by their cylinders help to explain the trend of practice in engine construction, which, beginning with single cyl-



A .B

Fig. 7g.—Diagram of the operations in the two revolutions of a single cylinder 4-cycle engine. A, the first revolution; B, the second revolution. As indicated, the working stage occupies only 140° out of a total of 720°. The exhaust valve closes at 5° after head centre, or after the beginning of the second revolution: the inlet opens 5° later. The same timing is shown on the other cycle diagrams in this chapter.

inders has seemed to be leading toward the block construction as the final form. This tendency, however, is combatted by the fact that air-cooled cylinders cannot be made successfully other than single, and as air cooling undoubtedly is increasing in favor, with high grade constructors, particularly of business vehicles, it is quite certain that the single-cylinder construction (not the single-cylinder engine) is growing in favor. So also is the four-cylinder construction in water-cooled engines, because this form permits a single water jacket to surround all the cylinders, and thus simplifies the amount of piping and pipe connections needed if two or more cylinders or groups of cylinders are used, to form the engine.

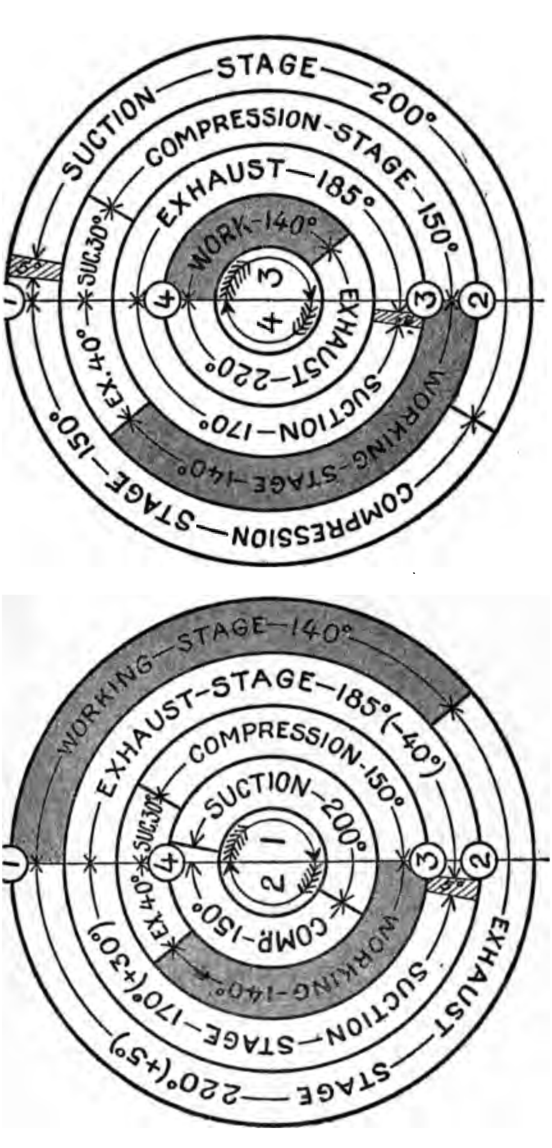


Fig. 7h.—Diagram of the operations in the two revolutions of a four-cylinder, 4-cycle engine. A, the first revolution; B, the second revolution. The perpendicular lines divide each revolution into two successive halves. The cylinders fire 1, 3, 4, 2; showing a total of 560° working stages, out of 720° for the two revolutions, or 160 without power impulse.

Block-Cast Engines.—Among the advantages of the block-casting construction, first used in multiple-cylinder form by Duryea in 1896-7, is the compactness and strength derived from a small amount of metal. Since the three or four or more cylinders forming the engine are combined in a single casting, they are held absolutely rigid, one with the other, perfectly parallel, if once properly made, and require but a very light crank case to hold and enclose the crankshaft. Although it was possible to produce single cylinders in the foundry, and handle them in the machine shop, with smaller equipment, and in a more economical manner than the block casting can be handled, foundry practice has im-

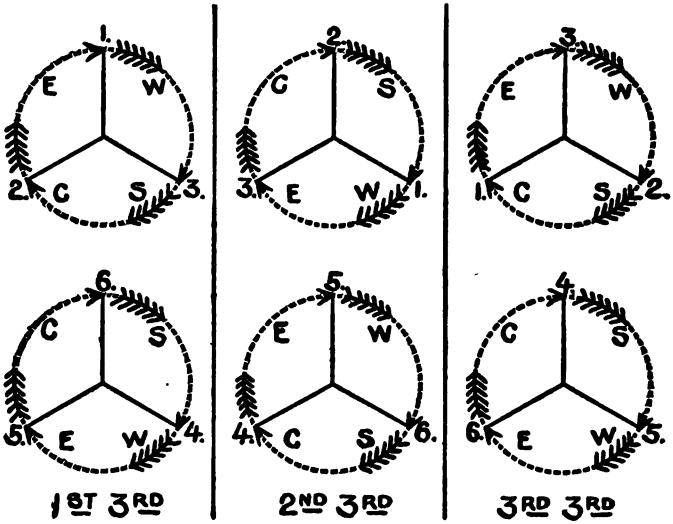


Fig. 7j.—Diagram showing the cranks and stages in a six-cylinder engine through one revolution beginning with the working stage in the first cylinder and the inlet stage in the sixth cylinder, and continued by thirds of a revolution. The numbers indicate cranks driven from respective cylinders, the letters stages in the cycle. Firing, 1, 5, 3.

proved, so that complicated castings are now produced with little waste and few blemishes, most of which blemishes can be removed by autogeneous welding or similar method if they exist.

Improved Factory Equipments.—Further, the large factories are now equipped with special machines for handling multiple-cylinder block castings as a unit, and finish them practically as quickly and accurately as the single cylinders were finished in the earlier history of the industry. On these accounts the advantages of the multiple-cylinder form are to

be had, even in the cheaper, lighter cars, and the maker of the single-cylinder car finds himself unable to produce his product proportionately cheaper, while certainly it is not comparable from the point of smooth running, easy cooling, small but regular impulses, and similar advantages which follow the large number of cylinders. It will thus be seen that the industry is influenced not only by what manufacturers think the public desires, but by the state of the manufacturing art, and the equipment of the various factories. Consequently, the question of whether to build engines of one, two, three, four or six cylinders cannot be settled off hand, or by theoretical considerations, but is a problem which

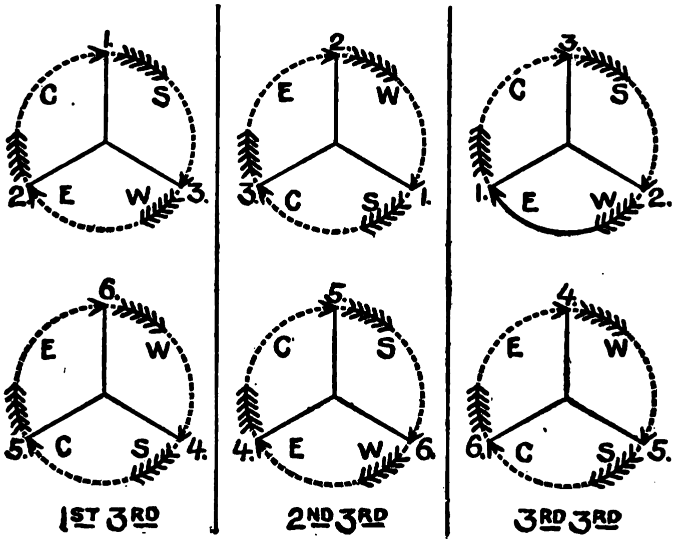
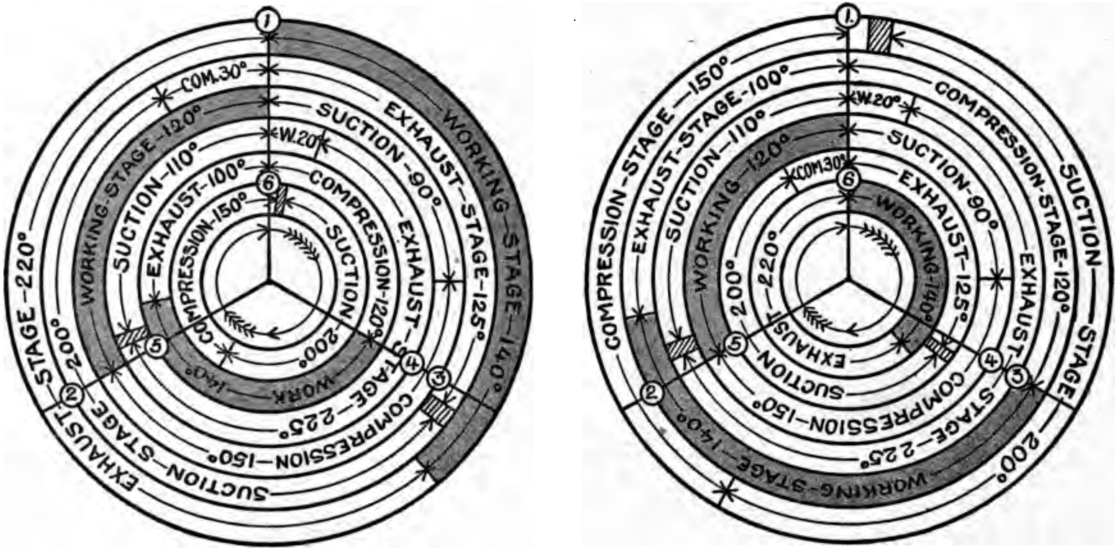


Fig. 7k.—Diagram showing the cranks and stages in a six-cylinder engine through one revolution beginning with the inlet stage in the first cylinder and the working stage in the sixth cylinder. Each third of a revolution represents 120°, bringing the succeeding crank to top position. Firing, 6, 2, 4.

the maker of the vehicle must decide for himself in view of the conditions under which the goods are to be produced and sold, and the buyer may choose any of these numbers of cylinders turned out by first class makers with a certainty that they will give him satisfactory results almost without question, and that if such results are not forthcoming the fault is not due to the number of cylinders, but to some other feature not considered here.

Proportions of Bore and Stroke.—When the gas engine was first applied to automobile practice, designers followed



A B

Fig. 71.—Diagrams of the stages of the cycle in a six-cylinder engine through two revolutions; A, the first revolution; B, the second revolution. Showing the nearly constant power effort. In the first third is seen 20° of power effort in the fourth cylinder and 120° in the first, followed in the second third by 20° in the first and 120° in the fifth; and 20° in the fifth and 120° in the third driving the third third of the revolution. Similarly in the second revolution. Cylinders fire, 1, 5, 3, 6, 2, 4. The positions of the several cranks are indicated by the numerals in small circles.

stationary engine procedure, simply because there was no other guide, and there seemed to be in their inexperience no reason why any other shape should be adopted. Stationary engines of twenty odd years ago largely followed steam engine practice, and employed strokes much lohger than bores. This probably because it was easier to produce a long, small-bore engine than a short, large-bore one, a fact made true by the lack of large and high grade machinery for producing large cylinders. A further cause for small bore and long strokes is probably to be found in the fact that up to certain sizes no cooling of the piston is necessary, but as the piston of a gas engine reaches five to eight inches in diameter it becomes difficult to carry away from it the heat which is received by the piston head at each impulse of the engine.

Objections to Large Parts.—With the larger sizes of engine the piston is, of course, large, and the head thick. Thus, the heat is afforded a fairly easy path, by the great mass of iron, to travel toward the cylinder walls, and thus escape, but in motor vehicle service, where weight is decidedly objectionable, these thick piston walls were necessarily made thinner, and, being thin, were badly warped out of shape. Furthermore, they could not carry off the heat, and so became overhot at the center of the piston head, causing carbonization, preignition, and followed by short life, as well as irregular warping of the cylinder, and difficulty of packing. On these accounts, as well as that of following stationary-engine construction, the early automobile engines largely were, as before stated, of small bore and long stroke.

Advantages of the Short Stroke.—As inventors became familiar with the subject they awoke to the fact that the short-stroke engine could turn over its crank-shaft more rapidly than the long-stroke engine, because of the slower piston movement, and since the friction of the piston in the cylinder is one of the limiting features of a gas engine. They also saw that the short-stroke engine could be carried up to much higher rotative speeds than the long-stroke engine without exceeding the practical limit of piston speeds, and this seemed to be desirable.

Need of a Flexible Control.—While many of the early designers tried to build their automobile engines to run at a steady speed like a stationary engine, and attempted to secure the changes of vehicle speeds by changing gears, it was not many years until the throttled engine, first used by Duryea in 1894-5, was developed, and speed changing by throttling the motor became a decided advantageous quality which emphasized the need for engines of great flexibility, *i. e.*, engines of ability to run slow or fast, as the throttle position permitted.

The "Square" Engine.—This feature of flexibility emphasized the need for engines of high rotative speed and small piston speed, and therefore demanded short strokes, while to preserve the power the bores were correspondingly increased. The result is that for some ten or a dozen years engines were improved toward, or even beyond, the square form (*i. e.*, having the same bore as stroke). In the few instances designers went much beyond the square form, and a number of good makers' employed cylinders of appreciably larger bore than stroke, while, with others again, the bore equalled nearly twice the stroke. About this time French racing authorities recognized the folly of makers wasting their money to produce racing monsters of no value whatever other than to be larger, more powerful, and faster than a competing monster, and placed a limitation upon the bores permissible in their contests.

Reasons for the Long Stroke.—This stopped the growth of the automobile engine toward large bore and short stroke, which heretofore had been a natural, wise, and economical growth. It substituted instead a poorer construction which makers took up because each desired something larger and more powerful than the other, and this could only be produced by increasing the stroke, so strokes were at once lengthened, to two or three times the bore, loose-fitting pistons applied, and lubricating oil fed unstintedly. These proportions, while not considered first class automobile practice, gave surprising results, and have been more or less copied by makers who, wishing to follow the latest style, or not understanding the exact facts, chose to put such motors upon the market. Within a year or two thereafter the English government and some of the United States passed laws fixing the motor vehicle tax or license fee according to the horse-power of the engine, which for taxation purposes was estimated from the bore, and very naturally buyers and makers desired to escape this tax (recognized as more or less unjust) by the use of bores as small as possible. It is thus seen that the tendency of recent years toward engines of larger strokes and smaller bore has been an artificial one, caused by laws either of government, or racing authority, and not a natural, proper, and mechanical one, supported by the best judgment of the factory designers; also, that while there seems to be differences of opinion as to the correct proportion of bore to stroke, this difference is rather seeming than real, with every evidence indicating that in the absence of restrictions upon the bore by the authorities, the square engine, or even the engine having a larger bore than stroke, would have been the predominating form today, because of its superiority.

CHAPTER VIII.

THE GAS ENGINE CYLINDER AND PARTS.

Advantages of the Several Cylinder Shapes.—In the matter of shape of cylinder heads, there is a much less definite agreement. In the 4-cycle types of engine three common and general shapes exist: (1) the dome head, (2) the "T" head, and (3) the "L" head. In the earlier forms, largely copied from stationary engines, in which the valve chambers were made separately, machined separately, and afterwards clamped in place by cap screws and packed with gaskets, the "L"-shaped head was the most common. This was particularly true because the exhaust valve only was mechanically operated, and the suction-operated inlet valve was in almost universal use. Since the inlet valve needed no mechanical means for operating it, it was commonly located in the axial line of the exhaust valve, but with its stem projecting in the opposite direction. The cylinder, therefore, had a single port, or pocket, to one side, bored completely through parallel to the cylinder bore. Into the lower end, that is, toward the crank-shaft, the exhaust valve was mounted with its stem projecting toward the cam-shaft, which operated it, either directly or through suitable lift. The inlet valve was mounted in the same port bore, but projected in the opposite direction, and was very light, fitted with a light spring, and opened by the suction of the engine piston.

Mechanically Operated Inlets. — As the demand for higher speeds increased, designers sought to secure more rapid action of the valves by mechanically opening and closing them, the thought being that considerable vacuum was necessary to open the inlet valve, and that the resistance of the valve prevented the proper filling of the cylinder with mixture. Again, in the early days, the sizes of these valves, largely taken from slow-running stationary engines practice, were wholly inadequate to give the high speeds demanded

in automobile work, and any obstruction to the incoming charge seriously limited the speed of the engine. Consequently, designers saw in the mechanical operation of the valve the only solution.

Enlarged Inlet Valves.—Later years and later practices have shown that much larger inlet valves, in many cases twice or three times as large as the exhaust valve, and half the area of the piston, have produced speeds much higher than were believed possible in the earlier years; but this solution, although suggested by some designers, did not appeal to engine builders at that time, and the mechanically-operated inlet valve became the accepted form. There were some exceptions, however, some makers still persisting in the use of the suction-operated inlet, particularly on the smaller engines, such as motor cycle engines, which were designed to get charges sufficiently large for high speeds, and work with good satisfaction.

The Evolution of the "T" Head.—The final adoption of the mechanically-operated inlet called for either an overhead valve-lifting mechanism, or a much wider port, so that both inlet and the exhaust valves could be placed side by side with stems pointing in the same direction. Some makers objected to the number of cams, and the general thick arrangement of these valves along the same side of the motor, and by using "T" heads secured a balanced appearance, with the inlets on one side, and the exhausts on the other, camshafts being provided for operating each. This practice undoubtedly added some expense, and gained very little, if anything, in quality. On the other hand, it is practically certain that the "T" head cylinder contains more port wall, that is to say, more flame-swept surface, than does the cylinder having but a single port, even though that port is a wide one and contains two valves. There is an increased number of parts, with no increased advantages, and the cost, as well as the objection of complication, has tended to diminish the percentage of engines employing the "T" head.

Cylinder Heads and Valve Gears.—The theory of the heat engine demands that the cubic contents of the cylinder be as large as possible in proportion to the surface of the cylinder walls, and designers trying to secure this preferable shape have frequently employed the dome head, which is simply a rounded more or less hemispherical end to the cylinder proper. They have placed in this head the two valves with stems upward, that is projecting away from the crank-shaft instead of toward it, and, of course, have been obliged to operate these valves by rocker-arms, or valve-lifting mechanism, somewhat more complicated than the usual form, or else by an over-head cam-shaft carried across the tops of the cylinders instead of down at their base within or without the crank case. This over-head placing of the

cam-shaft was found to be objectonable because of difficulty of lubricating, and exposure to the heat of the cylinders, as well as more or less noise of the operating parts. The latter feature was also connected with the over-head rocker-arms and similar valve-lifting mechanisms. As a result of this experience and these objections the modern 4-cycle engine seems to be settling down to that form having both the valves on one side in a wide "L" head port with cams on a single cam-shaft, and the valve stems, lifters, and cam-shaft enclosed behind a cover on the cylinder side or in the crank case proper. The enclosure of these parts puts the mechanism where it can be well oiled, and therefore insures long life, keeps out grit and dirt, and, further, insures silence, by having such noise as comes from even properly-made, well-oiled, and well-protected parts, housed, so that it cannot escape sufficiently to be objectionable to the user of the car.

The Use of the "L" Head.—Having arrived at this more or less generally admitted superior shape for the 4-cycle engine considerable thought has been given to the shapes of

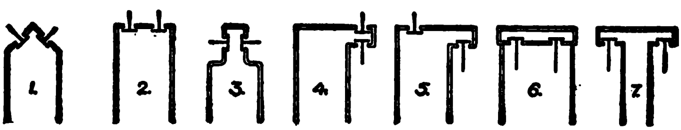


Fig. 8a.—Diagrams of cylinder head shapes, arranged in order of increasing wall surface; 3, 4 and 5 being about equal. Showing also positions of the valves. 1, conical head, 2, flat head, 3, extension head, 4, L-head with valves opposed, used with automatic inlets, 5, L-head with one valve in the flat top, 6, L-head with valves parallel, familiar with positively operated inlets using a common cam-shaft, 7, T-head with valves opposite, using two cam-shafts.

the port and cylinder-head walls best suited for getting the cooling water properly disposed about them, for making the valves and valve caps easily accessible, and for designing, generally, so that production may be a simple and inexpensive matter, and repairs or replacements easily made. That the "L" shape is not the best theoretically is well known, of course, but, all things considered, it is the best compromise available in the 4-cycle engine using poppet valves.

Cylinders for Two-Cycle Engines.—In the 2-cycle engine the question of cylinder shapes has not been so thoroughly worked out, for the reasons that the number of makers employing the 2-cycle engine have not been large hitherto, and that the 2-cycle engine, in its familiar construction, presents no valve problems. Employing, as it does, the moving piston, as a valve for opening and closing its ports, there is no question as to the shape of the cylinder head, but, in nearly all instances, the head is made dome-shaped, unless the designer prefers some modification to accommodate a specially-high or peculiarly-shaped deflector, or unless the cylinder is

open ended, when cast, being closed by a head, more or less flat, bolted in place. In general, the dome-shaped head is accepted as the proper one, and, undoubtedly, it more nearly meets the theoretical requirements accepted by gas engineers than any other form. That it is the most practicable way of meeting these theoretical requirements speaks much for its probable future acceptance, and renders it worthy of consideration by the student of gas-engine theory and practice.

Improved Valve Mechanisms.—As before mentioned, variations in the practice of engine designers, with respect to the placing and operation of the engine valves, as well as with respect to their size and the speeds attainable by their use, tempted designers to propose other methods of securing suitable valve action in engines of the 4-cycle type. One of the most noted of these, the Knight sleeve valve, has won a considerable adoption, and secured much attention by its performance during the past few years. It has been adopted by a number of representative automobile concerns on both sides of the water, and, if it has done nothing else, it has called the attention of the public to the limitations of the poppet valve, and this will undoubtedly result in either radically improving the valve action of the 4-cycle type of engine, or in eliminating valves altogether, as in the 2-cycle type. In the Knight engine there are no valve pockets, but the cylindrical shape of the cylinder is carried somewhat higher than the piston, with a consequently more or less flat cylinder head. This shape, while getting rid of the valve pockets, does not secure the theoretically desirable spherical shape of the head so fully as it is secured in some of the dome shaped heads. Further, the Knight valve seems to involve greater difficulties in the matter of cooling the piston, because of the two sliding sleeves between it and the cylinder wall, which, each coated with an oil film, must necessarily interpose considerable resistance to the passage of the heat from the piston to the outer wall, and cooling jacket. The great advantage of the sleeve type of valve; namely, the rapid opening and closing of the ports, which, being quite long in the circumferential direction of the cylinder, permit the gases to escape quickly, largely makes up for the difficulty of cooling by allowing the gas to escape so quickly that the engine does not become so hot as it otherwise must.

Other Non-Poppet Valves.—No other success in any line escapes imitation; consequently, the success of the Knight sleeve valve awakened a host of inventors and manufacturers, trying to secure the same or better operation for their mechanism. As a result of these experiments many engines have been produced with a variety of valves. The sleeve idea has been worked into a number of forms employing both single and double sleeves, some operated from the bottom end of eccentrics, as the Knight, others from the top end, some revolving around the cylinder in-

stead of sliding up and down, and other valves, like the piston valves, located outside of the cylinder, but in a port thereof, much like the poppets, while still others, like the rotating disks located in the head and opening and closing the ports in their movement as the Reynolds, and others like the Duryea as shown at the New York show in 1907, consisting of but a single shaft lying across all the cylinders, and by its rotation opening and closing passages into the cylinder. The rotary motion is undoubtedly to be preferred, provided the results are equivalent to those obtained by other means. The rotary valve seems to offer a simple, cheap, and almost frictionless solution of the 4-cycle valve problem, while it introduces no new problems in the matter of ports or cooling, or inertia. Just what the outcome will be in this matter of valve design, or what the shape of the future cylinder head, suitable to accommodate the style of valve yet to become general one cannot say. Certain it is that agitation of the matter is calling attention to the defects and will bring good results.

Metal for Cylinders.—While almost any metal will serve, after a fashion, for a gas engine cylinder, the early Wintons, for example, being made of bronze, it is a generally accepted fact that cast iron is preferable for this purpose, for the reasons (*a*) that it contains much free graphite carbon, which seems to help in lubrication and (*b*) that it resists heat and distortion better than many metals, and (*c*) that it is easily produced, and easily worked. On the other hand, many designers, working for light weight, have used various metals; some, for example, employing steel tubes for the cylinder walls, the heads either screwed or brazed in place, with reasonably good results, others using a steel casting, which, if of proper variety, shows superior results and greater strength than cast iron. The matter of strength, however, does not enter so largely, because defects in engine cylinders consist less in lack of strength, than in lack of ability to remain in true and proper shape. That is to say, when the engine cylinder is hot its size and shape are considerably different from what it was when cold, and this affects the quality of the engine much more than the average buyer suspects. A 4¼-cylinder often expands as much as $\frac{1}{32}$-inch in diameter.

Methods versus Metals.—To minimise this variation in shape due to heat, it is a very common practice to grind, or ream, or broach, the water cooled cylinders with steam or hot water in their jacket spaces, so as to heat them virtually, to working conditions, and thus finish machining them to a true shape while hot. This practice is undoubtedly good, and is employed by some makers of air-cooled engines, who play a gas flame on the exterior surface of their cylinders and raise them virtually to working temperature, while the interior is being finished by grinding exactly parallel, and

to their size. It is quite probable that more importance attaches to the securing and maintenance of shape, when the cylinder is hot, than to any difference of material, of which the cylinder is formed; although it is well known that some iron expands and contracts much more under heat than other iron, and that, therefore, some cylinders warp, lose their shape, and cause excessive heating much more because of this greater expansion and contraction. Stiffening the cylinders on their outer surfaces by grooves or flanges is also good designing, and is probably of more value to the user than differences in quality of material.

Separate Cylinder-Heads.—In many lines of mechanical work the product has been dependent upon the means for producing it, and has taken its shape largely from the shop facilities at the hand of the maker. Thus, in the early steam engines, the cylinders were open at both ends, because this permitted readier boring, and, after the cylinder boring was finished, a head, usually a flat disk, would be attached by bolts or cap-screws. Such method of attaching the cylinder head was quite common in automobile practice ten years ago, the only difference between gas engine and steam engine construction being that the gas engine was water-jacketed, and, in order to keep the head properly cool, it also must be made hollow, and have suitable water connections. To avoid duplicate connections with added complication and lessened beauty, it was usual to have passages from the cylinder water-jacket to the hot water space, which would permit the space in the head to fill with water from the cylinder, or *vice versa.*

Gaskets and Metal Joints.—These heads were usually fitted with a gasket of asbestos or other paper, perforated at the proper places to permit the water circulation. Too frequently these paper gaskets were softened by the water, and, when the engine was used, the softened gasket would blow out at one or more places, making a disagreeable and power-decreasing leak. To avoid this, builders adopted the practice of fitting metal to metal by careful machining, followed by scraping and grinding with emery or similar abrasive. The metal-to-metal joints gave little or no trouble, when properly fitted, although, in time, the warping of the metal might cause them to leak and necessitate additional grinding. This practice, while adding somewhat to the cost of construction, was, and still is, considered good workmanship, being used in many places where joints are necessary and gas pressures must be resisted. In some cases, the joints, instead of being fitted flat, were made conical, or otherwise, laid one in the other, so as to localize the grinding upon a definite and not very large surface; it being generally recognized that, for packing purposes, a small surface properly fitted is better than a large surface badly fitted, and that no great amount of surface is needed

to hold the pressures common in ordinary gas-engine work. Where flat surfaces were used, it was quite common to groove them to provide "gripping points" for the packing, which, when forced into these grooves, did not blow out so readily as when the surfaces were perfectly flat.

Later Constructive Practices.—Later constructions and the fact that automobile engines are usually not large, together with the use of a better class of machine tools, permitted makers to build their cylinders open at one end only, the head being integral with the cylinder at the other end. This arrangement contributed to light weight, because the metal usually employed in making the joint was not needed. It also permitted a better shape of cylinder head, that is to say, one more nearly hemispherical, and offered advantages in the location of the valves or similar parts that were quickly accepted by up-to-date builders. On the other hand, and of late years, since the multiple cylinder engine came into general use, some makers have been again using the open-ended cylinder, and fitting a single head to the entire block of cylinders; this single head requiring no more water connections than each head would require if applied separately. These long multiple heads, covering a block cylinder casting, can readily be piped around the joint if this method is preferred, but with modern machine methods there is no great difficulty in producing fairly tight joints and many makers employ this construction.

Objections to Removable Heads.—In a few instances, the cylinder has been practically a tube with the head bearing against one end, and the crank case, or cylinder base, against the other end; bolts extending from the crank case to the cylinder head drawing the three parts together. This construction is not so common nowadays for two main reasons. The first was that the bolts exposed to the air did not become hot so quickly nor so fully, as the cylinder walls, and so expanded less, with the result that they became excessively tight, often straining when the engine was hot, while when it was cool, they might be loose, not properly holding the parts. The other reason is that removing the head loosened the cylinder on its base and this was sometimes not desired, while the material required in the bolts added something to the weight. Later and better constructions confine themselves to lugs cast on the cylinder bottom, which are bolted or cap-screwed to the crank case, while studs or cap-screws or other means at the top secure the head in place if the head is removable.

Tapping in the Head.—A number of makers, preferring quality to cheapness, have made very light cylinder heads, very strongly attached by tapping the open upper end of the cylinder and screwing the head into this threaded portion, just as a pipe plug is screwed into a pipe fitting. Usually

it was not considered best to depend upon the threads for the fitting but conical surfaces were carefully machined or fitted by grinding, so that when very lightly screwed into place these conical surfaces came together so tightly as to insure perfectly tight joints and yet permit quick removal of the cylinder head for cleaning, inspecting the piston, or removing the piston and connecting rod upward through the top of the motor. In such constructions the entire cooling was derived from the jackets surrounding the cylinders, and the center of the head, like the center of the piston, became quite hot. But since the piston is not exposed to outside air as is the head, it should be very evident that any engine which does not overheat the center of its piston head can successfully run, without danger of overheating the center of its cylinder head, both being uncooled. Some makers using such heads, fitted the spark plugs to the center of the head, but this exposed the spark plug to a needlessly high temperature, and caused rather more troubles with the porcelains, or other insulations, than are found, usually, with plugs in cooler localities.

Heads Cast Integral.—A great majority of engines now in use have the head cast integral with the cylinder, and the water jacket carried up over the top of the head. It is quite common, for casting purposes, and, sometimes, for assistance in machining, to have a hole through the center of the head which is afterwards closed by a plug. The water jacket likewise has a hole concentric with this one in the cylinder head but usually much larger so as to permit ready access to the head plug and hole into the cylinder. Since water pressure is never large, it suffices to clamp or screw a covering over the large water jacket hole, and this is the common practice.

Integral Head and Water Jacket.—When the water jackets need cleaning this large opening is quite advantageous, because when the cover is removed much of the water jacket can be reached and scraped or otherwise attended to. Large openings into the water jacket are advisable, because cast iron is often porous, thus, small leaks may exist, which, if the part can be reached, may be plugged in any suitable manner, thus making the cylinders serviceable. In some engines the valve cap openings pass through the head into the valve ports, and are surrounded by the water jacket space, but, because of the large size of the valves, or for the purpose of ready cleaning of the interior of the cylinder, they are made larger than the admission of the valves requires. In the Stevens-Duryea, for example, the opening is oval and large enough to admit one's hand. The opening admits both valves, and extends completely across the valve port. It provides, therefore, a very handy and ready access to the cylinders. In recent Cameron engines the valves were placed above the head, lying opposite each other

in a horizontal direction in a vertical port or valve pocket. This arrangement secured, not only a fairly small port, but permitted inspection and cleaning of the entire cylinder head, by reaching alternately through one or the other of the valve openings.

CHAPTER IX.

The Gas Engine Piston.

Piston Construction.—The piston is the part which receives the pressure of the expanding charge of burning gases and conveys this pressure by the way of the connecting rod to the crank of the engine. Primarily it is a movable diaphragm across the cylinder, and, as such, it needs be only a circular head or disk. In gas engine practice it is usually cylindrical in shape, having the disk, or head, at one end and the other end open. Into this open end projects the connecting rod or pitman, which is attached to the piston by means of a transverse pin called the piston pin, or, better, the wrist pin, because of its wrist-like action at this place, as the crank revolves.

The Length of the Piston.—The fact that the piston has no guides, other than its own length, makes it necessary that the cylindrical portion be long enough to avoid any cocking or binding in the cylinder, as it would do if very short. Pistons, therefore, are usually a diameter long, or even a diameter and one-quarter, or one-half. If quite long, it is common to reduce the area of the cylindric portion by turning it slightly below size between the ends, leaving simply enough surface at each end, to afford proper wearing surface and insure long life. The thought is that the turning-down of the central portion lessens the friction of the piston against the walls of the cylinder. It also provides a space in which more or less oil gathers, and thus assists in lubricating the contacting surfaces.

Piston Grooves and Rings.—Into the cylindrical portion of the piston are placed grooves of rectangular cross-section, to receive the piston rings. These grooves should be deep enough to afford a strong surface against which the ring may bear, and, by a close contact, form a gas-tight joint between the ring and the side of the groove, so that

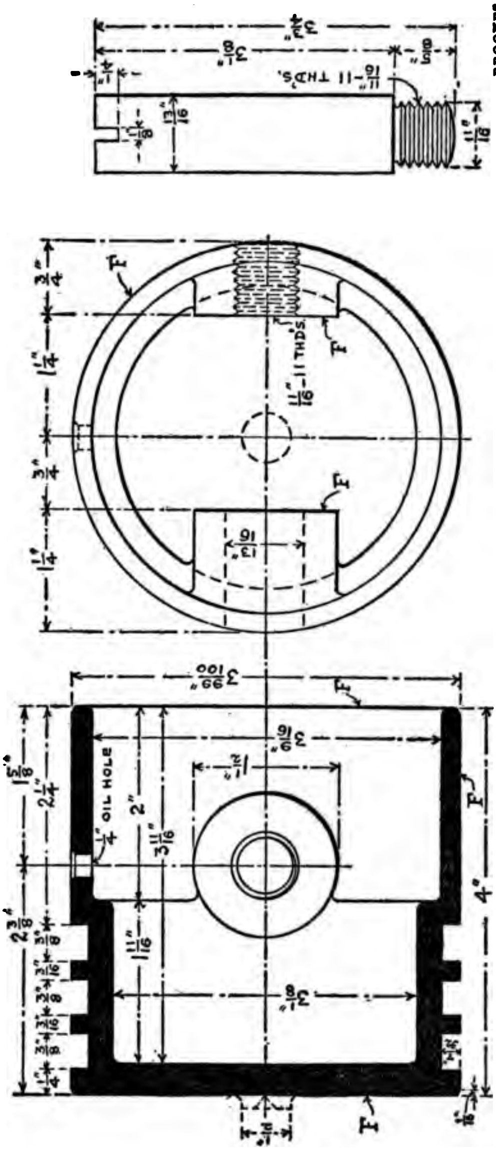


Fig. 9a.—Sectional diagrams of a typical piston for a four-inch cylinder; showing structural details and dimensions; also piston pin with screw insertion.

gas may not get past; a sort of valve as it were. The width of the groove is not a matter of fixed practice, but varies within considerable limits, being usually from two to four times the thickness of the ring, and carefully made, so that the ring, which is usually ground to size, may fit freely but as nearly gas-tight as possible. Free fitting of the ring is essential, in order that the ring may follow the walls of the cylinder, and prevent the escape of gas between them and the cylinder walls; which escape would result in loss of pressure and power, waste of fuel, and overheating of the parts.

Number of Piston Rings.—The number of grooves and rings is a matter of choice very largely. Some of the best makers use but two, while others fit their pistons with four

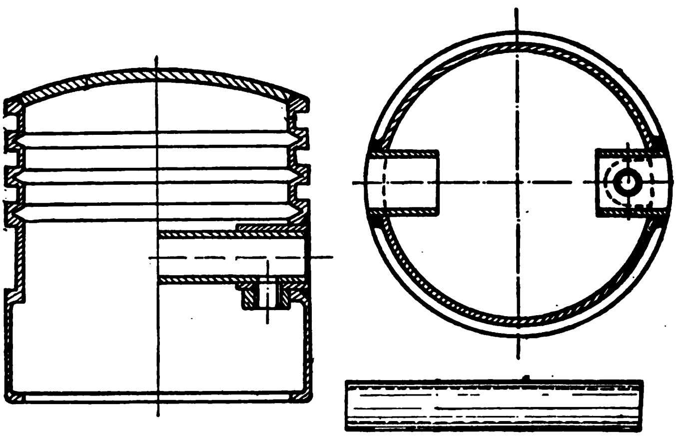


Fig. 9b.—Sections of a piston built up from a tubular casting, showing method of assembling the elements by autogenous welding; also hollow tubular piston pin.

or five. Generally these rings are placed as closely to the top of the piston as may be, but some makers fit one or even two at the bottom, or open, end of the piston in the belief that such a placing better regulates the oiling of the cylinder walls, and, by being well filled with oil, insures a tighter piston-packing, than if at the top, where the heat is greater, the oil thinner and the warping of the cylinder and piston walls greater.

Balancing the Piston.—It is common to place the wrist pin below the upper set of rings, which usually brings it about mid-length of the piston. This results in distributing the wear about evenly over the whole piston surface. At

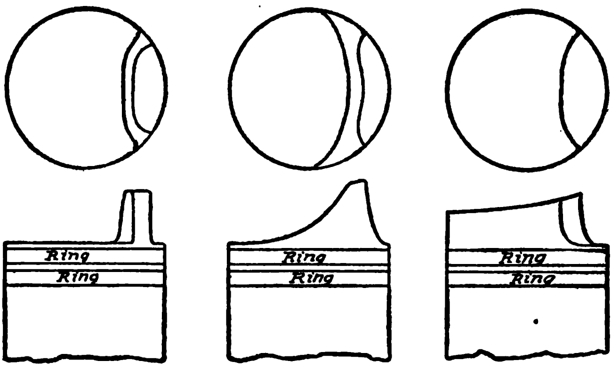
the place where the pin is to be fastened, bosses are cast on the interior surface which are bored to receive the pin; and above these bosses toward the piston head extend webs, which brace the bosses and stiffen the pin, to take the power thrust, without distorting the piston walls materially. These same or similar webs quite often extend across the piston head, and support it from deflection under the force of an explosive charge.

Shape of the Piston Head.—Thus far pistons differ but little. When we consider the head-end, however, much difference is to be found. In vertical engines it is quite common to make the head slightly domed or convex. This is done both to afford strength and to shed oil, which would, otherwise, pile up on the head and burn, or carbonize, owing to the heat to which it is exposed, and to the fact that the center of the piston head is the most difficult part of an engine to cool properly. In small engines it is common to make the head flat, because the thickness of the metal offers sufficient strength, and the heat is easily gotten rid of. In horizontal or inclined engines the concave, or cup-shaped, head is best, because it increases the cubic content of the compression space without increasing the amount of surrounding wall. It is more easily cooled than the other shapes and resists distortion even better than the convex shape. That it cools more easily may be understood, because the connecting ribs are shorter and it is closer to the walls of the piston, than is the convex form. As everyone knows, pressure on the outside of a dome distorts it, whereas pressure inside of it tends to round it up, as may be seen by considering an inflated toy balloon.

Holding the Pressure.—It is a mistaken notion that the piston holds the pressure of the gases. The piston offers the surface against which this pressure acts, but it is the packing rings which render the working space gas-tight, or nearly so, and on them, rather than on the fit of the piston, depends the perfection of operation. This makes it plain that the shape of the piston is not of great importance, and that its distortion, under heat or pressure, is not a serious matter, unless it is so great as to interfere with the proper performance of the packing duty of the piston rings.

Pistons for Two-Cycle Engines.—The above facts relate to the pistons of 4-cycle engines which are very generally alike. When we consider the piston of the 2-cycle engine, we find a greater variation. This is due to the fact that the pistons in such engines act as valves, also as deflectors for the in-coming and out-going charges, and it is customary either to shape the heads to secure this result or to provide deflectors on the heads which perform the desired functions.

Varieties of Deflector.—The more common form has a head more or less nearly flat, on which stands a vertical deflector of approximately U-shaped cross section, or plan. This vertical wall catches the in-coming new charge, as admitted through the transfer port, when the piston nears the bottom of its stroke, and throws the stream of gas up towards the cylinder head, causing it to push the old gases ahead of it, and down to and out of the open exhaust port. Another very common form has this deflector embedded in the cylinder head in such a way that only one surface is exposed to the gases. The other surface is formed by the more or less sloping head of the piston, which facilitates the flow of the old gases toward the exhaust port.



A B C

Fig. 9c.—Several piston head shapes used in 2-cycle engines: A, flat head with narrow deflector suitable for slow speed work; B, sloping head with wide deflector ends to prevent gas passing by them; C, built-in deflector.

Valve in the Piston Head.—Some pistons are provided with valves through the heads, which admit the new charge from the crank case directly into the cylinder, instead of carrying it outside and in through the piston-opened port in the cylinder wall. In such cases it is quite common to have the piston head provided with a conical deflector, which throws the new charge into the head of the cylinder, while the old charge is passed down all around the walls and out at the ports. Some two-cycle engines have two or more inlets, and a like number of exhaust passages placed oppositely, with the view of allowing the gases to get in and out more easily, but this arrangement seems to facilitate the mixing of the old and new charges, and is, therefore, not to be commended.

Other Two-Cycle Pistons.—Many other forms could be mentioned, but most of them are more or less experimental, and, while having points of merit, seem not essential to describe here. They indicate, more than anything else, the vast field to be explored by the builder of 2-cycle engines, before he will have reached perfection in this promising line.

Weight and Metal of Pistons.—Since the piston makes two movements during each crank-shaft revolution, coming to a stop at the end of each stroke, it is self-evident that it should be as light as possible, and, if convenient, also balanced by an opposite piston or similar weight. On this account considerable care is taken in piston construction, as well as in the selection of the material and in its working. Probably no part is more carefully thinned to the last ounce of strength, or scrutinized for defects in the material. Cast iron is the most common material, although steel castings, or even wrought steel, has been used by some constructors. Many attempts to use aluminum or some alloy metals have been made, and with more or less success, but not with wide adoption, owing to the fact that aluminum and its alloys lose strength, when heated to the working temperatures of a gas engine.

CHAPTER X.

GAS ENGINE PISTON RINGS.

Function of the Piston Rings.—Contrary to common belief it is the ring, and not the piston, which holds the compression and prevents the gases from leaking past the piston. The piston takes the major part of the pressure and transmits it to the connecting rod, but, if there is not a good tight joint between the piston and cylinder wall, the pressure escapes and the work is not done. The ring closes the space around the piston and makes the joint tight.

Finishing the Cylinder.—This statement of the situation sounds very simple, but, in reality, it is a complicated matter. Great care is taken to make the cylinders both round and of the same diameter throughout; that is, cylindrical. They are ground to the thousandth part of an inch. They are usually finished by lapping with some very fine abrasive substance, such as emery or pumice stone, or powdered glass, or some variety of sand, usually fed with kerosene. And then they are put into service and heated up to varying temperatures. In this process they undoubtedly warp, more or less, and distort, to some extent; with the result that the ring must expand in size as the top, or hot end, of the cylinder is approached and forcibly contract by being dragged down into the smaller end on the return stroke.

Operation of Piston Rings.—If one were selecting a spring to perform such a movement from 1,000 to 2,000 or more times per minute, he would hardly choose the shape of a piston ring or the material commonly used, cast iron. Yet cast iron piston rings give splendid service under such conditions. It is only when we call upon them for rather too great a range of accommodation that they fail, and we hear the engine pound, feel it lose power, and awake to the fact that it is "too hot." Increasing the cooling efficiency usually prevents further great distortion of the engine

cylinder, also prevents a recurrence of the trouble. Feeding more oil usually stops the openings which the piston ring fails to close, and also acts as an apparent cure. Stiffer rings often succeed in doing the duty required of them, where the less stiff rings fail, but they wear out themselves and the cylinder walls faster than rings less stiff.

Conditions of Good Fitting.—The desired condition is that the cylinders be finished to size at the working temperature, or as nearly so as possible, to the end that, when working, they may be both round and straight (cylindrical), when in use. When this is done, the ring simply follows the wall, with no great changes in position or size, and so packs tightly at every point. If the cylinder has expanded

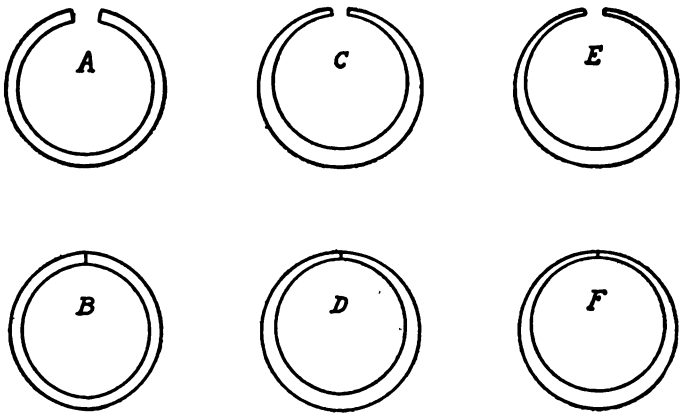


Fig. 10a.—Piston ring construction. A, concentric ring open, B, concentric ring closed, C, eccentric ring open, D, eccentric ring closed, E, eccentric ring finished, open, showing imperfect circles inside and outside, F, eccentric ring finished, closed, showing true circles inside and outside.

because of the heat, until it is larger in diameter at the top, it will be seen that, at high speeds, the rings do not have time to open up to the cylinder diameter. Consequently, they do not pack tightly at the upper part of the stroke, where the compression and explosion pressures are highest, and, therefore, the engine both loses power and overheats. Further, the work on the walls, tending to force them back into their grooves, in the short time allowed on the down stroke, must take power and cause both wear and heating, due to the friction of the ring against the walls.

Forming of Piston Rings.—Since the rings are in reality valves, closing small but important passages between

the wall and the piston, the importance of close-fitting surfaces must be recognized. The outer or circumferential surface does not require the care or skill in making that the edges do, for it is exposed to rubbing action in use, and this generally smooths and wears it, where rubbing hardest, until it becomes a nice fit. The edges, exposed to no sliding action and simply bearing against the walls of the ring groove, must be properly fitted in the beginning, if they are to work properly. On this account, it is most common to grind the edges of the rings to insure a perfect surface, while the grooves are turned with great care and accuracy.

Effects of Warping.—That the piston warps and expands is not of much moment, since its cylindrical shape largely prevents it from distorting in a lengthwise direction. Consequently, the grooves retain their ability to carry the rings and maintain a tight joint, as long as its edges are in good shape generally. Expansion radially is of small

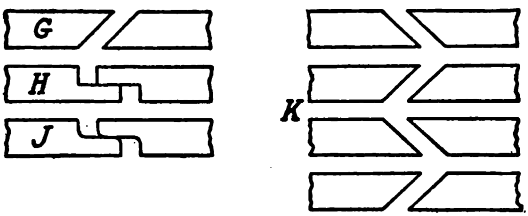


Fig. 10b.—Piston ring cuts. G, diagonal cut, H, stepped cue, square ends, J, stepped cut rounded ends, K, diagonally cut rings arranged in line to show proper method of alternating oppositely cut diagonals.

importance, so far as the effect on the ring is concerned, because the ring is loosely held in the groove in that direction, and it is the springiness of the ring, and not the size of the piston, that maintains the ring against the wall surface. There are exceptions to this statement, however, as shown by the action of a piston which fits the cylinder so loosely that it shakes from side to side, as the angle of the connecting rod changes. In moving it carries the ring away from the wall faster than the ring, already working hard to follow the wall, can accommodate. This effect is particularly noticeable when the rings fit tight in their grooves, or are "burned" in place, being held by the carbon which has accumulated on them. It is also evident that, if the piston fits too loosely, the gases have more room to pass by, making use of any passage that may exist, as, for example, the usual cut or joint in the ring, where its ends come together.

Design of Piston Rings.—The usual piston ring is a ring of cast iron, which is turned to a size about 1/80 of the piston

diameter larger than the cylinder bore. It is then cut through at one place, leaving the ends free, with sufficient space between them to permit of closing down to the cylinder-bore size. Generally this cut is left larger than this, and is finished down to the exact size by closing, gripping in a clamp and then turning or grinding until the outer surface just fits the cylinder. This makes a ring which fits well and has sufficient elasticity to follow the walls closely.

Reasons for Ring Eccentricity.—While many very good rings are made as above, it is the more common practice to turn the ring with its inner and outer surfaces eccentric before cutting. It is then cut through at the thin part, and, when so made, it will be found that the stiffness at the thick part largely compensates for the loss of strength at the cut. Consequently, the pressure against the cylinder wall is nearly the same at all points. That is to say, the pressure in a line at right angles to the diameter, through the cut and thick side, is nearly as great as the pressure in the line of this same diameter. To be more explicit, the cut ring resembles a letter C, and, if one tests it with the fingers by squeezing it vertically, the effort to bend the thick back of the ring is nearly equal to that required to bend both top and bottom portions by squeezing in a horizontal direction. That a concentric ring is not of equal strength all around is easily seen by again looking at the letter C, and noting that the vertical squeeze is resisted by only one thickness of metal, while a horizontal squeeze is met by a thickness of metal at the top and another at the bottom. In the Wasson piston ring the metal is of equal thickness all around, but, at the back, is rendered stiffer by a mechanical peening, which is graduated so as to stiffen the metal of the ring where stiffness is most needed.

The Piston Ring Joint.—Much ingenuity has been expended on the opening, or cut, of the ring, commonly termed the "joint." The more common cut in automobile engine practice is the *diagonal*, at about 45 degrees. This leaves each end terminating in a point, which, having less surface than a square end, wears more rapidly, and does not cut or scratch the cylinder walls, as a square end probably would.

The next common cut is the *step*, or *lap* joint, to produce which the ring is milled into from opposite sides by cutters, as wide as the lap desired, and set, not directly opposite, but in such fashion that the cutters, when cutting, are on opposite sides of a line across the ring. When these cuts reach the center of the ring, there is no metal between the cutters. Consequently, the ring parts, and the remaining metal forms the lap joint, when the ring is placed in the cylinder. The advantage of this construction is that there is no joint, or gap, along which even a small amount of gas can directly pass, from above to below the ring, when in service. This

advantage is not so great as it might seem, because the cuts are always made where the rings are thin, and thus they do not fit against the bottom of the ring groove. This leaves an opportunity for the gases to pass into the opening at one end of the joint, behind the joint lap and out at the opening at the other end of the joint; a route not exactly direct but so nearly so as to be of very little advantage in actual practice. Some makers fit a plate under the joint, which plate is the full width of the groove, and, if pressed against the inner surface of the ring, completely closes the opening. A thin piece of steel, like a clock spring, is sometimes applied in this manner, to improve both the tightness of the joint and the elasticity and packing ability of the ring.

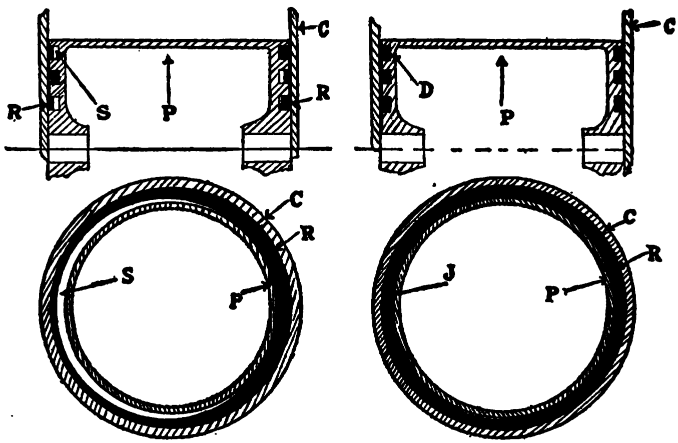


Fig. 10c.—Diagrams showing the action of an eccentric and a concentric piston ring. P, the piston; R, the ring; C, the cylinder wall; X, the clearance behind the eccentric ring, often filled with oil and soot.

Improved Piston Ring Designs.—Much ingenuity has been expended in making rings, offering some advantages over these commoner designs. One kind is made by making numerous cuts into the ring, from opposite sides with a fine saw, but never cutting quite across the ring. This is an expensive ring to make, and, while it has no joints that extend completely across the ring, the objection is that the gas may enter at the joints, on one side, and escape at the joints on the other, by passing behind the body of the ring, and thus destroy most of the expected value. Another form termed "Leak-Proof" consists of two rings, each of L-shape section, but placed together, so that the joints are opposite, and the back of one "L" forms the inner surface, while the back of the other forms the outer surface. This

construction, while twice as expensive as the common ring, actually reduces the open-joint space very materially, and also insures a fairly even pressure all around the cylinder. Whether such a ring can follow the inequalities of the cylinder, as fully and rapidly as the more common kind, is doubtful. But for engines, in which there is no great expansion and warping of the cylinder walls, it seems to be well worthy of attention. Still another form is made doubly wide, and then split, so as to form a ring of double the length, but of half the width. There is an uncut portion joining the edges of the nearly separated rings, and the loose ends, of course, stop short of this uncut portion. This ring cannot be other than tight, so far as direct passage of the gas is concerned, but, as it wears, the gas can pass under it, as in the lap-joint ring. The movement required of this ring, in expanding and contracting, would seem to render it unsuitable to cylinders having much variation in size between the top and bottom ends. In a few cases, the rings have been made in pieces, and each lap jointed to the next, with a spring behind it, to force it outward. This construction, copied from large steam engine practice, has not seen wide adoption in automobile practice.

Metal of Piston Rings.—While cast iron has been the usual metal for piston rings, some constructors have used steel rings, and it would seem that, with the growing demand for light rings and pistons, this practice would increase. Steel rings would seem to be more lively, less likely to stick in their grooves, and better able to follow the irregularities of the cylinder walls. In a few instances, bronze or brass has been used, and, while this makes a very smooth ring, easy on the cylinder wall, it seems unable to stand the heat and friction so well as cast iron, or a harder metal. Some experimenters have used Babbitt metal, hoping to get a very frictionless ring, but the heat of the usual automobile engine is such that this type of metal seems unfit.

Edges of Piston Rings.—In general, the edges of the rings are made square and sharp, so as to scrape the oil in front of them, and, by causing it to pile up in front, to secure a perfectly tight joint; which they could not do, if their edges were rounder. Some designers take advantage of the fact that a beveled edge will lift the ring over the oil on the cylinder surface, and, by providing such an edge on the lower sides of the rings, succeed in carrying a much larger amount of oil up toward the cylinder heads. This both assists in packing and in oiling.

Piston Rings and Lubrication.—From this discussion it will be seen that oil is a very necessary adjunct of the piston ring, being rather more necessary to assist in packing, than for lubrication purposes. This is particularly true in a gas engine, where there is no steam to condense

and assist in packing at the rings, as in a steam engine. Experiments have shown that it is possible to lubricate an engine perfectly by using graphite, but to get the perfection of ring surface that could hold the pressures was a far more difficult matter. This fact makes plain the value of an oil that will retain its body under heat, in order that it may add to the ability to pack and hold the gases. Some designers make use of the ability of oil to pack by cutting a series of small grooves or scratches, around the piston, between the rings or below them, and thus get a more even distribution of oil, as well as carrying more of it up towards the head end, which is the more difficult end to lubricate. This practice also reduces the amount of friction surface, and slightly lightens the piston. It is not applicable, however, to the pistons of 2-cycle engines, since the grooves permit the passage of gases from the transfer port around the piston to the exhaust port.

CHAPTER XI.

THE PISTON PIN AND ITS INSERTION.

The Piston Pin.—The connection between the piston and the upper end of the connecting rod is effected by a straight pin, commonly called a "wrist pin," because of the wrist-like action, at that place. Generally, this is a straight pin passing through the piston, at about mid-length, and lying parallel to the crank-shaft and crank-pin, so that, as the lower end of the connecting-rod swings to and fro in the crank circle, the upper end may freely oscillate on the piston pin. In the earlier constructions, these pins were usually made solid, and not of large diameter, but, as engine speeds and powers increased, so the need for larger bearing surfaces increased, until today the majority of piston pins are hollow, being made either from tubing, hardened and ground to size, or from solid bars bored axially to lighten the weight.

Insertion of the Piston Pin.—While in general, the piston pin is driven tightly into the piston, and firmly supported in bosses cast on the interior walls of the piston, there are some exceptions, in which piston pin bearing surfaces are provided in the piston bosses, and the pin is fitted solidly to the end of the connecting rod. In the more usual construction, any tendency of the pin to spring under the thrust of the explosion expresses itself also in a tendency to distort the walls of the piston, whereas, if the pin turns loose in the piston bosses, its springing is less likely to affect the piston, and, consequently, secures better action of the piston rings and better packing.

Pin Insertion and Cylinder Shape.—Most designers, however, believe that the exact shape of the piston is not of great importance, and that the slight deflection, due to pressure on the piston head, and against the piston pin and connecting rod, does not distort the pin and the piston walls sufficiently to be objectionable. Opposed to this be-

lief is the fact that pistons are now being made lighter than ever before, and are thus more easily distorted. Consequently, the practice of stiffening the piston pins against distortion, by making them larger and hardening them, is growing. These large diameter pins would be quite heavy, if not lightened in some way, which accounts for the use of hollow construction. Usually, these pins are made from steel tubing, which can be either tempered or case-hardened, and is, then, made perfectly true and to exact size by grinding.

Securing the Pin to the Pitman.—When the pin is fastened in the end of the connecting rod, or pitman, it is quite usual to provide this end with a set-screw, or clamping-screw, in order that the pin may be firmly held against movement. This is important, because a loose piston pin will often work its way to the one side or the other, and, projecting against the cylinder walls, scratch them so deeply as to allow the gases to escape and the engine to lose in power. To protect against this danger, some designers have closed the ends of the piston-pin openings by fitting in bushings from the outside; these bushings being usually of brass, or other soft metal, which, even if loose, would not seriously damage the cylinder walls.

Securing the Pin to the Piston.—In the more common practice, wherein the piston pins are fixed firmly in the piston walls, it is common to fasten them in place by screws, passing through the bosses into the hollow of the pin, and prevented from turning or backing out by inserting cotter-pins through their points. Such fastening fixes both ends of the pin to the piston, but, while exceedingly firm, is objectionable from the fact that expansion of the piston, due to the heat of the working charges, does not, at the same time, and to the same extent, expand the piston pin. Consequently, the result is that pistons are often expanded into an oval shape, their shortest diameter being parallel to the piston pin. This slight defect may be largely overcome by leaving one end of the piston pin unfastened, so that, as the piston expands, this end may slip or yield slightly, and thus permit the piston to retain its cylindric shape.

Pins with Split or Taper Ends.—Some designers split one end, or even both ends, of the piston pin, and provide a taper screw, by which the split end can be expanded tightly in the piston boss. This adds somewhat to the expense, but is a superior way to insure against loose piston pins. In other constructions the pin is slightly tapered at each end, one end being larger than the other, so that, when driven into place, the pin takes a firm bearing in the piston. It may, however, be easily removed by lightly driving it back, when desired.

Pins with Rotative Bearings.—In some cases ball or roller bearings have been employed on the piston pins, but the motion at this point is so slight, and the pressure so high, that this practice has not found much favor. Roller bearings, however, work quite well at this place, because the oscillating motion has no tendency to cause the rollers to creep or roll out of parallel with the shaft, as they sometimes do with bearings, wherein the motion is continuous. It will be seen that, whereas a ball bearing cannot get the balls twisted, since they are spherical, a roller bearing, having sufficient slack or insufficient guides, may get the rollers out of line enough to make them creep endwise, and so bind against the end supports, or even to bend or break them, because, when out of line they no longer rest their whole length against the shaft. Such tendency to disalignment is not common at the piston pin bearing.

Oiling the Piston Pin.—Oiling of the piston pin is a problem that attracts considerable attention, because of the heat to which the piston is exposed, and, also, because of the inaccessibility of the parts. Some designers, using hollow pins, make one or more holes through the pin, near its center, and depend upon oil from the cylinder walls, scraping into the hollow pin, and reaching the bearing surfaces through these holes. Most designers, however, depend upon splash from the crank-case, together with the more or less oily mist constantly floating in the crank chamber, to carry oil to the piston pins. Other designers, again, more ambitious, employ a scoop at the lower end of the connecting rod, with a tube extending the length of the rod, so that oil, caught by the rapid revolution of the lower end, is forced through the tube to the piston pin. In some cases, more elaborate means, involving check-valves, are employed, but usually the splash system serves perfectly, and the more complicated devises are not needed.

CHAPTER XII.

THE PITMAN OR CONNECTING ROD.

The Pitman or Connecting Rod.—The pitman or connecting rod extends from the crank pin to the wrist or piston pin. One end travels around in the circle described by the crank pin; the other, working on or over the piston pin, moves up and down in a straight line. The former bearing works with a revolving shaft in it, while the latter simply oscillates on the pin. Both work mostly on the downward strokes, and, because of this fact, have ample opportunity to fill with oil, and be ready for the next hard stroke. Notwithstanding all this, the connecting rod bearings probably give more trouble than any other bearings on the engine, and designers are building them larger, and of better material, each year.

Weight and Shape of the Pitman.—Like the piston, the pitman is a moving part that must be considered in the balancing of the engine, and its weight is of great importance. On this account it has usually been made as light as possible, with the result that, too often, it proved to be of short life. Various sections have been used for the rod portions, in the attempt to get light weight and great strength. The solid oval rod has found much favor with many designers, but has largely given away to the I-section which seems lighter for a given service. The X-section and the U-section have been used with good success, but not with such economy of weight as the I-section. In cases where specially light constructions have been sought the tubular rod has been used, but this necessitates more machine work at the ends and brazing, or other method, of fastening the bearing portions with the result that the cost is much higher, and the uncertainty of service much greater.

The Piston End of the Pitman.—In automobile practice it is customary to make the upper end of the pitman solid,

and to bore it out to the size of the pin, if the rod is of bronze; if of steel, to bore it out large enough to receive a tubular bushing of bronze or hardened steel. This bushing is of such size as to fit the piston pin and run thereon without adjustment. When so much worn as to be noisy, this bushing is driven out and a new one put in. This is a very

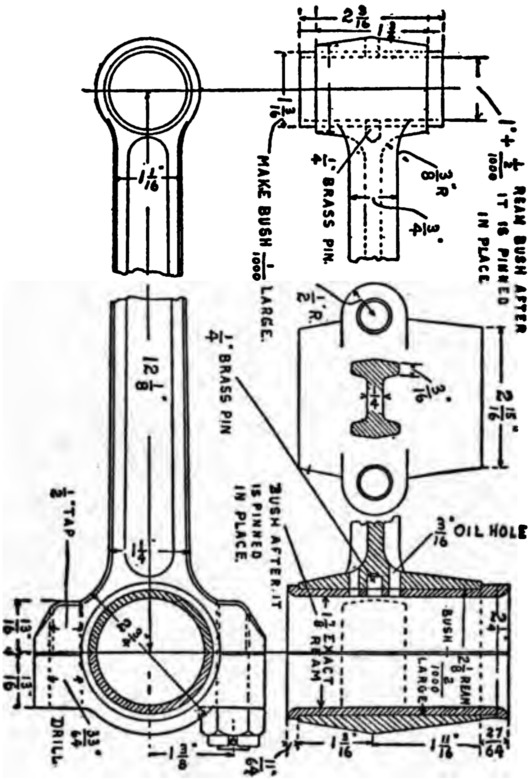


Fig. 12a.—Diagram of a typical pitman made from I-section rod; showing details and dimensions.

satisfactory arrangement, and it works out with less cost to all parties than a more complicated bearing, which, while adjustable, would be more expensive to build. In bronze rods it is not uncommon to split each end on one side, and to provide a screw for drawing the cut together; thus providing an adjustment by pinching the bearing together.

Rod and Wrist Pin Integral.—Some rods are built with the pins integral, to be fitted into the piston loosely. Such a device, doubtless, is less likely to spring and distort the piston, when under strain of an explosion, and, thus, has much to commend it. Bushings are fitted into the enlarged holes in the piston walls, and, by being removable, enable the T-headed rod to be put in position, also to permit its renewal, when worn. These bushings are often closed at their ends, and so prevent leakage from outside the piston into the interior, as may happen in a 2-cycle engine or in a 4-cycle having a ring at the bottom.

The Crank End of the Pitman.—The crank end of the rod is larger than the piston end, and is made with more care, not because it has more pressure to support, but because it has the speed of revolution of the crank-shaft, in addition to the piston pressure. To get it onto the crank pin it is usual to split the end to form a loose cap, usually held in place by two or four studs, and suitable nuts, which are rendered secure by being castelated and cotterpinned. In some cases bolts through the lugs are used instead of studs. The studs, however, are lighter and generally more satisfactory. In one form one side of the cap is hinged to the rod end, and the other side only provided with a bolt. This permits adjustment by tightening up one bolt only, and is of some advantage from that point of view. Usually, however, the fit of the studs in the lug holes on the adjusting side of the bearing is not so tight as to prevent one side being tightened up, without changing the other. Consequently, this easy adjustment is not an advantage over the usual form, while the double number of places to adjust insures a longer life because greater range of adjustment to the studded or bolted forms.

Bearings on the Pitman.—At the crank-pin end it is common to fit bearings of Babbitt or bronze, or even rollers, which can be taken out and renewed, when necessary, and thus prolong the life of the rod. In some instances ball bearings have been employed, but the heavy thrust, which is exerted against these bearings, is rather against the use of ball bearings, because of the large size and expense attendant upon the use of such size. Further, the difficulty of getting a well-made ball bearing into place has been a fairly good reason why such constructions have not been more largely adopted. Designers recognize that every ounce of internal friction, which they can do away with, contributes to that extent to the available power, and so have striven to build the frictionless motor and nowhere have they worked harder than on connecting rods.

Loose Bearings.—In a few instances the bushings have been left loose and free to revolve in the rod end as well as on the shaft. This is a form of enlarged bearing surface

which deserves greater recognition than it gets. By this arrangement the bushing revolves at some speed lower than the shaft revolution and both shifts its position in the rod end and on the shaft. In short, each bearing surface has an average of but half the usual speed, which is much the same as doubling the bearing surface area. That this practice has not been more general is rather an indication of unfamiliarity with its advantages than of objection to it.

Length of the Pitman.—Rod lengths are a much discussed matter. How short it may be made is the question constantly asked by the designer. In automobile practice he is constantly trying to get light weight and great compactness, and so keeps the cylinder short as well as the engine stroke. A considerable difference in practice is found. Rods have been made as short as 1½ times the stroke, and give good service, particularly where the crank-shaft is offset from the cylinder axis line, so that the angularity of the rod on the working stroke is not so great. Rods 2½ times the stroke are almost equally common. Probably 1⅞ to twice the stroke is a fair average of usual practice.

CHAPTER XIII.

OFFSETTING THE CRANK-SHAFT.

Advantages of Offsetting.—Offsetting of the crank-shaft center is used in connection with gas engines, for the purpose of increasing their efficiency, by reducing the friction of the piston against the cylinder wall; by permitting the use of a shorter connecting rod, with shorter cylinder, and, consequently, a more compact engine, and by permitting a higher average piston speed. It was first introduced by Duryea in 1897 and is now used by many first-class automobile builders. It is applicable to the gas engine, because this engine in automobile practice is seldom or never made reversible, or, if made reversible, as are some 2-cycle engines, the loss during the short reversing periods, in operative conditions, is so small, as compared with the gain during normal use, that it may be neglected. In the steam engine, which runs with equal facility in either direction, the crank-shaft is placed in the line of the cylinder axis and the connecting-rod angles are the same on the working strokes, regardless of the direction of crank rotation; but, in the offset gas engine, the aim of the designer is to secure a better working angle of the connecting rod during the powerful working stroke, when the pressure of the piston against the cylinder wall is liable to be quite strong and thus cause considerable friction. Reference to a diagram will show that, on the working stroke, the connecting rod of an offset engine has first some angularity in one direction, then some in another and finally again in the first direction, whereas in the engine not offset the angularity of the connecting rod is always in the same direction and reaches a much higher degree than if the crank-shaft is offset. In other words, in the offset engine the connecting rod lies in the axis of the cylinder twice during the working stroke and does not vary largely therefrom at any time.

Neutralizing Friction and Dead-Centers.—From this description and a simple diagram it will be seen that the angu-

larity of the connecting rod, consequently, also, the friction of the piston against the cylinder wall, is much lessened during the working stroke. This is true with the crank-shaft offset, because this construction permits the use of a shorter rod, which in turn allows a shorter cylinder and adds to the compactness and light weight of the engine. There is another advantage, however, also evident from the diagram, and this is that the upper dead-center is not reached when the crank is vertical but slightly later, when the crank and connecting rod are in line, and that the lower dead-center is also not reached, when the crank is vertical, but when the crank and connecting rod are again in line. Since, however, the upper end of the connecting rod has taken a new position, not moving in a line toward the crank-shaft, but to one side of it, the two dead-center positions do not run directly

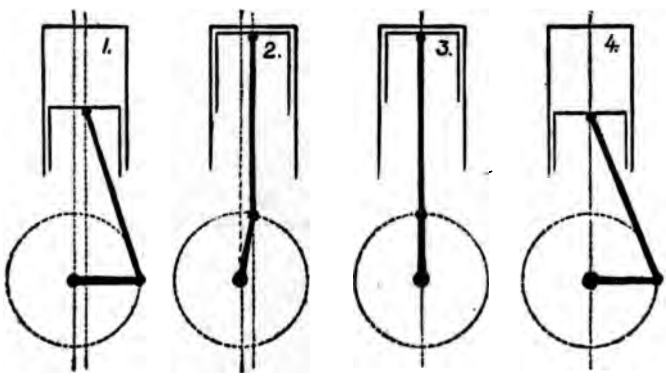


Fig. 13a.—Cylinder sections showing head center and half stroke on an engine with offset crank-shaft (1 and 2) and on one with centered crank-shaft (3 and 4.)

opposite, or in line with, each other, as in the non-offset engine, but at some angle dependent upon the amount of offsetting. The difference of these angles is added to the 180 degrees, commonly considered as the length of the working stroke; thus showing that the working stroke of the offset engine can be some degrees longer than 180 degrees, while the return stroke of the idle piston exhausting the gas is shorter than 180 degrees, and the piston speed, consequently, somewhat faster than on the working stroke. While this gain should be considered of some value, it is not customary to offset sufficiently to make this gain of great value, for reasons to be stated later.

Offsetting and Improved Lubrication.—The slower piston speed on the working stroke in the offset engine is an advantage, because automobile engines are run as fast as proper

piston lubrication will permit, and the working stroke is the one most difficult to lubricate, because the service is greater on that stroke. Since in the offset engine the piston is thrown first against one wall of the cylinder, and then against the other, and finally back against the first, there is a splendid opportunity to lubricate, much better, in fact, than if the pressure were continually against one wall on the working stroke. This fact, coupled with the slightly lower speed on the power stroke, permits higher piston speeds than in engines which are not offset, and is a decided gain. There is also a slight advantage in the fact that, as the piston travels downward on the working stroke, it travels to one side of and, to some degree, around the crank-shaft, so that, in reality, it partly follows the motion of the crank, thus working on the crank more effectively than if not offset. Here, also, the gain is small but such as it is it favors the offset engine.

Degree of Offsetting Used.—Engines have been constructed with offsets equal to the crank length, but, in order

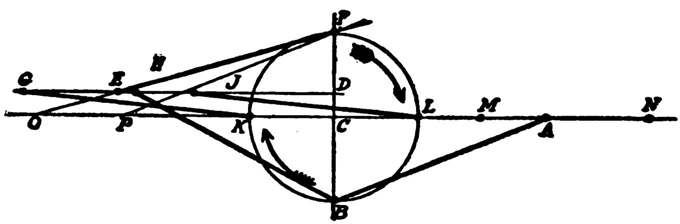


Fig. 13b.—Diagram showing the principles involved in offsetting the crank-shaft of an engine. Line AB shows pitman at 90° crank-throw on a centered crank engine, MK crank center, NL head center; GD line of offset from center line OC; EF line of pitman at 90° down-stroke, HB at 90° up-stroke; GK at head center, JL at crank center. Pitmans in both cases of the same length. Line PF equal to line AB on center line, showing smaller angle obtained by offsetting by comparing OF and PF.

to get room for the connecting rod to act, it has been necessary in these constructions to use large bores and short strokes; consequently, such amount of offset has found little favor. The leading thought of the designer is to get the connecting rod in the axis of the cylinder at the time of greatest average pressure and speed, which occurs near the upper end of the stroke, and, on this account, the offset is just enough to throw the connecting rod to one side of the centre line for a few degrees, and then to the other for a somewhat greater amount, by which time the pressure and friction have become much reduced. The difficulty of keeping the connecting rod out of contact with the mouth of the cylinder also influences the amount of offset, and, while connecting rods are sometimes curved or offset at their lower ends, to assist in clearing the cylinder mouth, this practice

not regarded with favor, if an appreciable amount of cutng or bending of the connecting rod is necessary. Comarison of a goodly number of engines using the offset crankaaft indicates that one-third of the crank length, or thereabouts, is good practice, with many examples of more or ss deviation from this measurement.

Better Running Due to Offsetting.—It will be seen that ot only is the downward stroke longer than the return roke, but that opposite positions of the crank do not give e same relative position of the piston, because of the difrence in angularity of the rod, and, that this fact affects e timing of the spark to some extent. It will be seen that e weight and inertia of the fly wheel insure a fairly steady ovement of the crank-shaft, and that, since the downward troke of the piston is longer than the upward stroke, beause of the added degrees already mentioned, which were ubtracted from the upward stroke, it is evident that the ston speed is slightly less on the downward stroke. The otal gain in power from this practice is quite small being timated as about one to two per cent., but, when it is reembered that this gain is secured without additional cost, ith some gain in lightness and compactness, and that it lso permits higher piston speed with better piston lubriation, also that the gain, even though small, is largely beause of friction saved between the piston and the cylinder all, it is well worth consideration.

Improved Accessibility of Working Parts.—Another adantage of the offset crank-shaft is the greater accessibility f the connecting rod and piston, which can be reached more asily from one side of the engine because the crank-shaft is ome distance to the opposite side. While there may be ome slight difference in the matter of balancing the offset ngine, this is so slight as to be unworthy of consideration, or the reason that the moving parts of the crank-shaft and nds of the connecting rod are substantially unchanged by e piston movements, and the fact that the upper ends of e connecting rods move to one side of the crank-shaft, instead of directly toward it, has so little bearing on the balancing of the revolving parts as to be negligible.

Offsetting and Pounding.—Some users have believed that e change of direction of the thrust from one side of the ylinder to the other during the working stroke is likely to ause "pounding" in the engine, but, with any reasonable orkmanship, the fitting of the piston to the cylinder is close nough to prevent this action, and no evidence has been ound to support this belief by careful investigators. It is ore likely that, with an extremely loose piston, sufficient ovement from one side to the other could be produced to ake a noise, but that this occurs in ordinary automobile ractice seems an ill-founded belief.

The Exhaust and Compression Strokes.—The advantage of a quick return stroke to expel the burnt gases has been explained, but the gain during the slower suction stroke is not so evident, although none the less real. It permits a slightly longer time to fill the cylinder with the new charge, while the quick compression stroke forces the new charge into the firing chamber, with little time for losing the heat of the compression. Indeed, the only objection to offsetting is that, on the compression stroke, the angularity of the connecting rod is greater than if the engine were not offset, but since the pressures of compression are but one-third to one-fifth, or even less, of the pressures of the working stroke, it will be seen that the loss due to the greater angularity is much less than the gain on the working stroke. These advantages and considerations have not been given full importance by many designers, but they need only be stated to be appreciated.

CHAPTER XIV.

The Gas Engine Fly-Wheel.

The Action of the Fly-Wheel.—The fly-wheel, often called balance wheel, acts as a reservoir of energy, into which power, in excess of the immediate needs, can be stored, to be drawn upon as required in the operation of the engine. While not a reservoir in the sense that it accumulates power to any great extent—as does, for example, a storage battery—it is highly effective within its limited range, in the fact that it stores the excess pressure of the moment of the explosion stroke, in the form of momentum, to give it out later, during the exhaust and other non-working strokes. The result is that the action of the engine is much more steady and regular than it would be without a fly-wheel. In fact, if an attempt were made to run the engine without a fly-wheel, it would almost certainly stop between the impulses of the explosions, while, if it did pass over an impulse, the powerful thrust transmitted into the gears, shafting, clutches, and other parts, would either be wasted by slipping the clutch, or would probably do damage by stripping off the teeth of the gears.

The Necessity of the Fly-Wheel.—If the application of power in a gas engine could be regular, as in an electric motor, or even so nearly regular as in a steam engine, it would be quite possible to run without a fly-wheel, as do most automobile steam engines. The instantaneous and quick-acting impulses generated in the cylinder of the gas engine are totally different from those generated by the other mentioned powers, and provision must be made for this difference. This is obtained by using small cylinders, and securing the necessary power effect by using several of them; also by using very large bearings, strong crank-shafts, and a good-sized fly-wheel, as before stated.

Attachment of the Fly-Wheel.—Because of this intermittent and violent-impulse action, the fly-wheel must be at-

tached to the crank-shaft in a very firm manner, which has resulted in the common practice of fitting the crank-shaft with special large-sized flanges, formed integral with it to which the hub of the fly-wheel is bolted; experience having demonstrated that keying the wheel hub to the plain shaft is often not a sufficiently strong construction for satisfactory automobile use.

How the Fly-Wheel Equalizes Operations.—Contrary to a more or less prevalent opinion, a fly-wheel is not a creator of power and does not add to the horse-power of the engine. Its sole object is to steady the running, catch and store the engine impulses before they can reach the driving mechanism and the vehicle and by their violence do damage thereto, and to give out this stored energy on the idle strokes or at such other times as it may be available. As already explained, the fly-wheel stores power as the engine is gaining in speed, the unused energy being transformed into momentum, and, when the load becomes greater than the engine is able to carry, at any given rate of speed, it slows down and a part of this fly-wheel energy is expended in overcoming the resistance. This is shown when one races the engine at the bottom of a hill, thus storing power both in the speed of the fly-wheel and in the speed of the vehicle, which partly carries the vehicle up the hill, this power being expended as the engine and vehicle lose their speed and momentum.

Fly-Wheel Diameter and Weight.—Since the fly-wheel is not a factor in the production of power other than an equalizer of impulses, its diameter is a matter of greater consequence than its weight. Its extra weight of metal may be put into an additional cylinder or two for the engine, thus adding effective power, without adding weight. This would lessen the vibration, because the cylinders, for a given size of engine, may be smaller, and, since there are several of them working consecutively, their impulses tend to maintain an even application of power. Constructors have learned this lesson quite fully in automobile practice, with the result that very few single-cylinder engines are now used on automobiles, and the number of two-cylinder engines of the 4-cycle type are proportionately less than ever before; while, at the same time, the number of six-cylinder engines of the 4-cycle type is constantly increasing. This tendency toward an increased number of cylinders arose from the mechanical facts above recited, but, it has, undoubtedly, continued because of the desire of purchasers and makers to have something believed to be better than previous productions. It is, therefore, to some extent, a matter of style, rather than of valuable and economical service. In engines of the 2-cycle type, which have no idle piston strokes, the need for additional cylinders is not so pronounced, since such an engine, having two cylinders, gives the same number of

power-impulses as an engine of the 4-cycle type, having four cylinders.

Danger of Too-Heavy Fly-Wheels.—Since the object of the fly-wheel is mostly to store the sudden impulse of the explosion and carry it over the idle strokes, thus making an even distribution, it is evident that a wheel large enough to do this is all that it required and that any additional weight simply adds to the weight of the vehicle without adding to its value. In fact, needless fly-wheel weight may detract from the value of the vehicle because the energy stored in the fly-wheel, if unduly heavy, becomes a factor of danger to the clutch, transmission, propellor shafts and joints, differential, rear axle and tires. This is owing to the fact that a heavy fly-wheel in motion continues that motion in spite of any unexpected resistance, whereas a light fly-wheel, meeting unexpected resistance, would slow down, or stop, before the teeth of the gears, or the strength of other parts, could be endangered.

Considerations on Fly-Wheel Design.—From what has just been said, it will be seen that there is a golden mean for fly-wheel weight, which should be sought by designers, to the end that the driving mechanism, including the tires of the road wheels, may be protected from the severe impulses of the engine and also not subjected to other, and possibly equally severe, strains from the excessive weight and power-storing capacity of a needlessly large fly-wheel. It is also quite evident that this golden mean varies according to the number of cylinders, or according to the frequency of the power impulses. Thus, in a single-cylinder engine, having one power stroke followed by three strokes which not only make no power, but actually take power from the fly wheel for their accomplishment, it is quite evident that a large fly-wheel is required. But in a four-cylinder engine, for example, in which there is an impulse in each half revolution, the need for a large fly-wheel is very much reduced, so much, in fact, that, in general, there is sufficient weight in the crank-pins and their connecting rod ends to continue the engine in motion if no fly-wheel is used. It is not considered practical, however, to operate a gas engine of four, or even of six cylinders without some fly-wheel to steady the action more than these slight weights could do.

Rules for Fly-Wheel Design.—In considering the amount of fly-wheel needed, two factors enter, viz., size and weight, both of which have been treated as a single element in the above description. It is evident that the size is doubly important, because the double-diameter wheel carries its rim-weight twice as far from the center, where, not only does it have twice the leverage, but also moves at twice the speed, with the result that it is practically four times as efficient as is the rim-weight of a single-diameter wheel. While, for

actual work, it is probable that fly-wheel weights cannot be varied *as the squares of their diameters*, but, preferably, by somewhat less than this, it is proper for this exposition to consider them capable of being varied in this ratio. This being true, it will be seen that, in order to secure light weight, it is advantageous to make the wheels as large as may be, to the end that needed fly-wheel effect may be secured with the least possible weight. In some cases, as for example in aeronautic engines, the fly-wheel rims have been large and heavy but attached to the hub by tangent steel spokes, as a bicycle wheel is constructed. This practice has not been common, however, because generally the fly-wheel is used for some other purpose, as, for example, to receive the clutch mechanism, and the light tangent-spoked wheel construction does not lend itself to such uses.

Practical Fly-Wheel Diameters.—Automobile fly-wheels vary considerably in diameter, according to the ideas of the designers. While, in some cases, they have been placed at the front of the engine, which is usually farther from the ground than the rear, and, therefore, permits a larger and lighter wheel to be used, it is usual practice to place them in the rear. This placing limits the size of the wheel, because, in current designs, the engine is vertical, with the cylinders above the crank-shaft. This brings the crank-shaft low, and a large fly-wheel would extend so much below the crank-case, that it would not clear the ground farther than is necessary. Owing to this limitation, the average fly-wheel diameter in American practice would probably be 18 inches, although some vehicles are equipped with fly-wheels of from 24 to 26 inches in diameter. At the other extreme are many small-cylindered engines using fly-wheels of from 14 inches to 16 inches diameter, while in boat work, where the weight is carried as closely to the bottom as possible, and, therefore, room below the engine is more contracted even than in automobiles, fly-wheels of from 10 to 12 inches are employed. These wheels, however, are made quite heavy, because in boat work the importance of saving weight has never been so fully recognized as in vehicles, which must travel the common roads. A still further decrease in size, and without great increase in weight, is to be seen in motorcycle engines, which usually have their fly-wheels enclosed in the crank-case, and, consequently, much limited in diameter. Such fly-wheels may be found as small as 8 or 9 inches diameter, for cylinders of 2¾ or 3 inches, or more, in bore.

Points on Fly-Wheel Weights.—Having decided how much room can be allotted to fly-wheel diameter, the designer next considers the matter of weight, and meets his ideas as to the needs of the engines by giving the wheel such weight as seems best. In this respect, also, practice shows nearly as great a variation, as there is in size. Indeed, there

seems to be no fixed rule by which fly-wheel capacity may be determined, for the reason that there is much flexibility in the engine itself, not to mention the fact that, in many cases, the vehicle becomes more or less a store-house of power. It will be seen that, at high speeds, very little fly-wheel is needed, while, at low speeds considerable energy is needed, to keep the engine moving until the next impulse.

Speed-Compensating Devices.—Some designers have contrived to overcome this need for fly-wheel weight at low speeds by providing means for varying the engine compression. The Adams-Farwell revolving engine is one of this type. The variant compression being secured by holding the inlet valve open, when the engine is throttled, so that the new charge pushes back into a distensible bag, formed in the supply pipe, which bag holds the unused mixture until the next suction stroke, instead of forcing it out into the atmosphere, and wasting it. This arrangement permits the engine to be turned over, for starting, with practically no compression whatever, or to run practically free, from either the slackening effect of the compression or the jerky impulse of even a light explosion, under high compression, and thus contributes much to the sweet running of the throttled engine. This Adams-Farwell revolving engine employs no fly-wheel but depends for this effect, upon the mass of the revolving cylinders, which is as great, or greater, than the usual fly-wheel weight.

Fly-Wheels on Motor-Cycle Engines.—In the motor-cycle engines, already mentioned as having such small fly-wheels, the designers aim to run at high speeds, and this enables them to avoid much need for a fly-wheel. Just how much fly-wheel should be provided for automobile service is, therefore, largely a matter of choice of the designer, who must decide whether he will save weight in the fly-wheel, or provide a steady-running engine at extremely slow speeds. If he can connect the engine directly to the road wheels of the vehicle, without slack or lost motion in the mechanism, as is done in the Duryea roller-drive vehicles, the mass and momentum of the vehicle serves perfectly for fly-wheel purposes, and very little fly-wheel effect is needed, excepting to assist in starting the engine.

The Fly-Wheel and Clutch.—Thus far the fly-wheel has been considered in its fly-wheel capacity, but common practice makes use of the fly-wheel in one or more other capacities, in which it serves perfectly. Hence, this double, or triple, use is to be encouraged. Some designers fit the common cone clutch into the rear surface of the fly-wheel, with the result that no additional room for the clutch is needed, and the strength of the fly-wheel spokes, or web, does double duty, serving also, instead of a wheel or web for the driving member of the clutch. With disk clutches, or with the

friction disk drive, this result is not obtained. Thus it is probable that the cone clutch has advantages from the constructor's point of view, because of this compact and economical combination.

The Fly-Wheel Used as a Fan.—A goodly number of constructors fit fan blades to the fly-wheel, or build the spokes of the fly-wheel, so that they serve as fan blades. This latter practice is not the best form, because the average cast iron spoke is not sharp enough on its edges to effectively slice into and impel the air forward, being so blunt as, to a greater or less extent, to strike and repel the air, just as a stick is repelled when one attempts to insert it through the round spokes of a rapidly revolving buggy wheel. In a number of vehicles a much more efficient fan arrangement is employed, which consists of blades attached to the rim of the wheel either on the periphery, where they act simply as the tips of propellor blades, driving the air outward and backward, or placed along one side of the rim, forming what is known as a "sirocco," or turbine blower. This turbine form is much more efficient, because the blades are placed near the periphery of the wheel, and their entire surface is fully active, whereas, in the ordinary propellor fan, having blades radiating from the wheel axis, the centers of the blades move too slowly to be of much advantage, and the air cannot be accelerated, as it is in the turbine form, where even the inner edge of the blade is moving at a rapid speed, and is shaped so as to scoop the air, which is thrown outward by centrifugal force, and is forced forward faster than the speed of the wheel by the shape of the outer part of the blade. We have consequent added efficiency, and the result that a very small blower or fan of this type moves a large quantity of air at a high velocity.

Position of the Fly-Wheel.—While it is most usual to mount the fly-wheel at the rear of the engine, very often with fan blade spokes some constructors place it at the front, where it may be made larger, and, also, where it may take air from the front of the vehicle and drive it backward, cooling the engine, instead of taking the air from around the engine and throwing it back under the vehicle. With a front-mounted fly-wheel, it is usual to arrange for fresh air to enter the engine enclosure near the tops of the cylinders, after which it may be guided down the cylinder walls, cooling the hot heads first, and thus keeping the lower parts of the cylinders nearly as hot as the tops, with a consequent gain in freedom from distortion, due to heating one end more than the other. This arrangement of the fly-wheel fan and movement of air is a most commendable one, and undoubtedly destined to grow in favor. In the Duryea two-cylinder 2-cycle engine the fly-wheel, with its blower at the side, is placed between the cylinders, as in some French engines, and the air from the blower is

directed by suitable casings to the cylinder heads and down over their walls, escaping near the base of the cylinders.

Fly-Wheel Position and Fan-Effect.—Designers differ as to the proper method, some believing that blowing the air upon the cylinders is more effective, others that forming a vacuum and allowing the outer air to flow in is a perfect equivalent. The difference seems to be that when the air is blown upon the cylinders it may be directed more nearly where it is wanted than when it is drawn away from them and allowed to flow in at every aperture naturally. No matter what the arrangement, this use of the fly-wheel is growing in favor. It replaces a special fan with bearings, blades, adjustments, and other considerable complication, and does the work more reliably and just as efficiently.

CHAPTER XV.

The Valves of a Gas Engine.

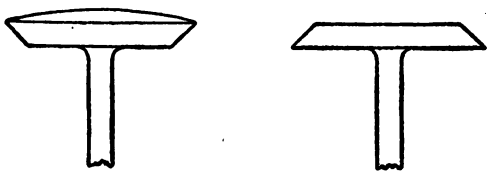
The Location of Valves.—A valve is simply a gate or door for admitting the gases into or out of the engine cylinder space. As mentioned in the chapter on cylinders, the location of the valves is a matter of choice with the designer, rather than of any inherent necessity. In engines of the 4-cycle type the valve location is usually at, or about, the head of the cylinder, but, in 2-cycle engines, it is not common to use valves in the usual sense of the word. The reason is that the piston serves as a valve, and opens and closes the ports at the proper time, the exception to this being the use of a valve into the crank case and occasionally one in the transfer passage between the crank case and the cylinder proper.

Automatic Inlet Valves.—In the earlier engines it was quite common to use a light inlet valve operated by suction of the piston, which valve, being light, timed itself,—that is to say, it opened, when there was sufficient suction to lift it, and closed, as quickly as its spring could carry it shut, after this suction ceased. As speeds increased, engines seemed to run away from the suction-operated valve, and designers fitted mechanically operated valves with strong springs, which were forced open at the proper time, and closed, as quickly as the operating mechanism would permit, regardless of the suction of the piston. So successful were these devices that the mechanically-operated inlet valve has become the standard and most commonly-used form in automobile practice.

Size of Inlet Valves.—Still not satisfied with the speeds thus gained, designers have continued their progress, until valves half the cylinder diameter are in use, and the end may not yet be at hand. As is quite evident, a larger diameter valve needs lifting but a short distance, to provide quite

a large opening, and this is true, whether the valve be operated by suction or mechanically.

Size of Exhaust Valves.—While the earlier engines were provided with exhaust valves larger than the inlets, on the theory that the hot exhaust charge required more space for its accommodation, because of its expansion, than did the cold and smaller incoming charge, it is recognized, at the present time, that the exhaust gases, being under considerable pressure, will escape through an opening smaller than that through which the new charge, coming in under atmospheric pressure, can enter. For this reason, most modern engines have both valves, exhaust and inlet, of the same diameter, which adds to the ease of construction, by lessening the variety of the parts. Since both valves are mechanically operated, the same size of stem, the same tension of spring, the same adjustment and the same valve-lifters, with slightly differently shaped cams, are sufficient for both. This condition does not hold true with suction-



Figs. 15a. and 15b.—Poppet valve shapes; A, coned valve, B flat valve, used principally for automatic inlet because of lightness.

operated inlet valves, which are made as light as possible, so that they may open at the lightest suction, and close with, or before, the slightest movement of gas in the opposite direction.

Considerations in Valve Operation.—When considering valves and their action, it must be remembered that the gases have considerable inertia, although, seemingly, without weight. Their small weight, however, multiplied by the high speed at which they must move, amounts to a considerable inertia, on which all good designers reckon, as fully as possible. On this account, the valve-lifting is done at such times as will insure the best passage of the gas. Thus, for example, the inlet valve is opened as quickly after the closing of the exhaust as possible, and is kept open, preferably, until the piston is returning on the compression stroke, the aim being to close the inlet valve, before any perceptible amount of reverse movement in the inlet passage is caused. As the end of the working stroke is approached, the exhaust valve is opened, the aim being to open it sufficiently ahead of dead center to allow the pressure contained in the cylinder to escape, so that, on its

expulsion stroke, the piston will find no needless pressure to work against. The amount of opening required to accomplish this result depends upon (*a*) the size of the valve (*b*) the shape of the passages, (*c*) the speed of the engine, (*d*) the amount of valve lift, and a few minor considerations in addition; but modern practice indicates approximately 40 degrees ahead of dead-center as the proper point at which to begin opening the valve. In slow-speed engines not intended for racing, 35 degrees is probably ample, but for racing or high speed work, 50 or even 55 degrees are sometimes used. The wide variety of practice at this particular point is largely due to the differences in construction of the remaining parts of the engines as well as to the different services for which the engine is designed.

Action of Poppet Valves.—The poppet valve, the form most commonly used, directs the gases from its conical seat towards its stem, and rather bunches or congests them in

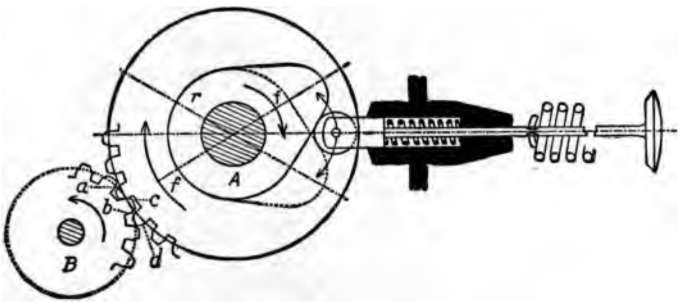


Fig. 15c—Diagram of the mechanism for lifting the poppet valves of a gas engine. As shown, the cam A, is at mid-position, or 30° from neutral. The tooth, *a*, on the driving pinion, B, is leaving engagement; tooth, *b*, is driving *c*. When *d* comes to position opposite *a* the cam will have come to its highest point. There are 60° between the positions represented by lines, *r* and *b*, or six teeth on the circumference.

the passage just outside the valve. This results in interference and lack of free escape, so essential to high speed work. Some designers have used flat-seated valves, but this shape accentuates the concentration mentioned, and is not so good as the conical seat usually pitched at about 45 degrees. One of the great advantages of the sleeve, the rotary and the piston valve forms is that they offer straight escape passages for the gas, rather than the concentric convergent paths offered by the poppet valves.

Valve-Operating Cams.—The shape of the cam has much to do with the exhaust valve action. At the time of opening there is a considerable pressure on the valve head, *tending to keep it* closed, and this pressure must first be

overcome by the lifting action of the cam. Most designers of engines have the cam-shaft directly under the valve lift so that the cam, in rising to lifting position, sweeps diagonally against the lift instead of rising straight against it. This results in much side strain, with consequent wear, and in a needless waste of engine power, in order to cause this wear instead of expending itself fully in lifting the valve. The aim of the designer is, as far as possible, to cause the base of the cam to wedge under the lift in the easiest

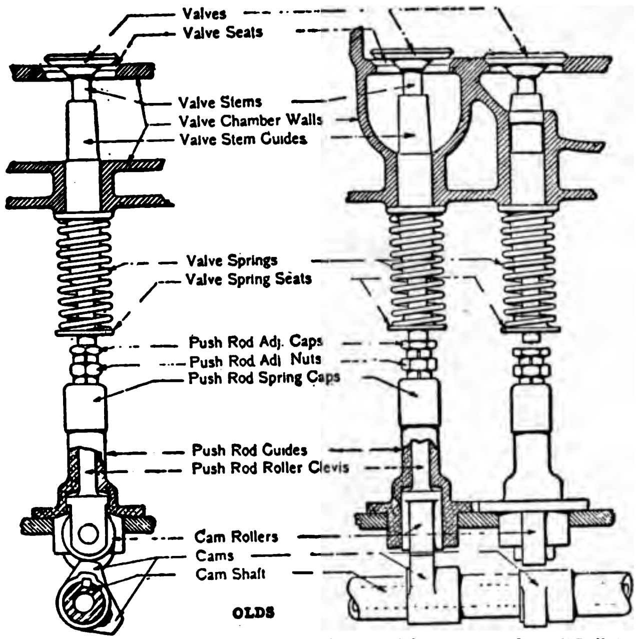
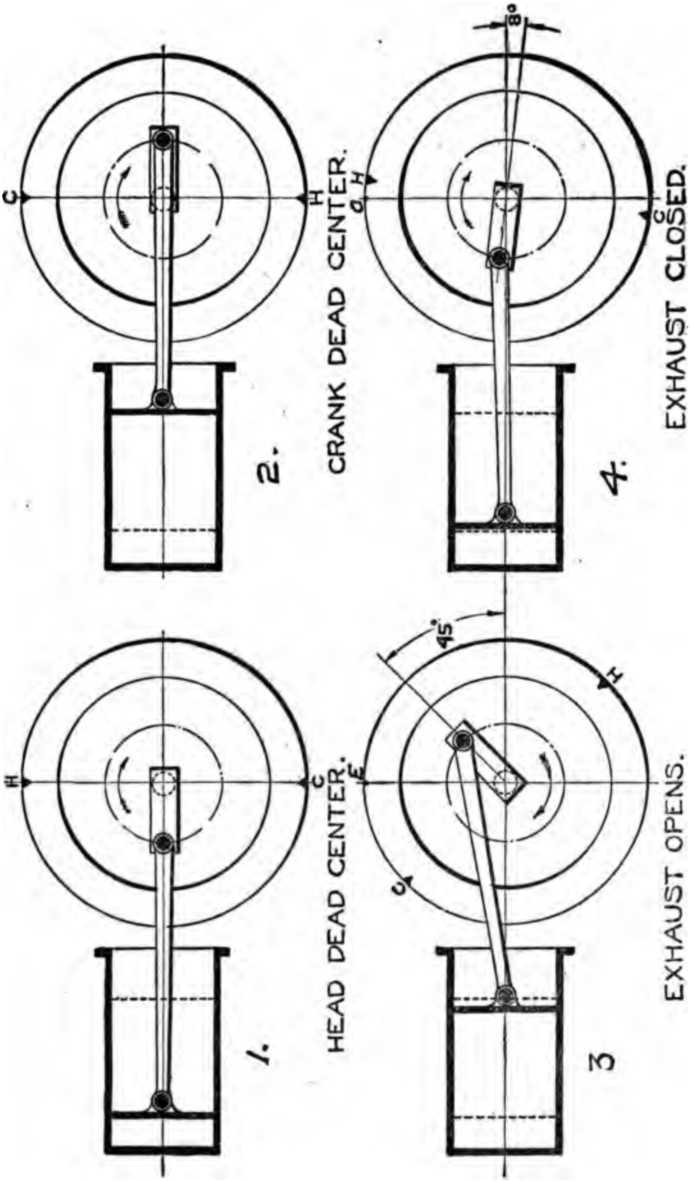
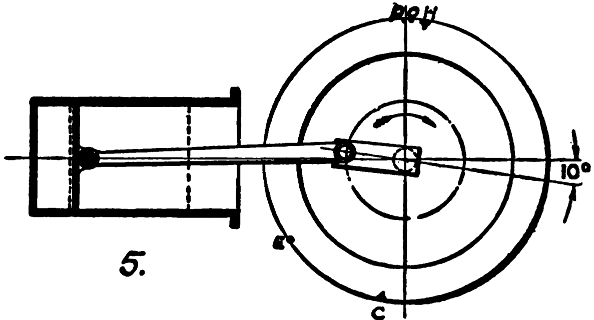


Fig. 15d.—Details of the cams and valve lifting gear of an "L" head cylinder; showing relative positions of the cams.

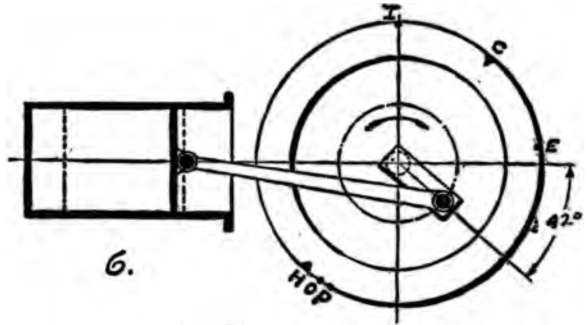
and most powerful manner, followed by a quick lifting action as soon as the valve has been forced off its seat. It will be seen that, once the valve is lifted, the pressure is partly transferred to the outside, so that the labor of lifting it farther is but a fraction of the original effort, as required to force the valve from its seat.

Improved Valve Lifts.—In the Duryea 4-cycle engines the cam-shaft, was offset from the line of the valve stem axis slightly more than the total valve lift, with the *result that the advance* surface of the cam was presented


1.
HEAD DEAD CENTER.
H
C
2.
CRANK DEAD CENTER.
C
H
3
EXHAUST OPENS.
45°
E
C
H
4.
EXHAUST CLOSED.
8°
a H
C



INLET OPENS.



INLET CLOSED.

OLDS

Diagrams showing the method of marking the rim of the fly-wheel to indicate the proper timing of the valves. Although this may be indicated in terms of piston position in inches before or after the beginning of strokes, it is more convenient to measure the positions in terms of degrees of arc on the rim of the engine fly-wheel. The positions necessary to identify are thus shown in the first two figures. Fig. 1 shows the position of the piston and crank at head centre, when the crank points toward the top of the cylinder and is in line with the pitman. This centre is indicated when the point marked H is at the top of the fly-wheel. Fig. 2 shows the positions of the piston, crank and pitman at crank dead centre, when the crank points directly away from the top of the cylinder. This position is indicated when the point marked C is at the top of the fly-wheel. These two points H and C having been found, the examination to determine the timing of the valves, and whether it is correct in any given case, may be made easily. Thus, as here indicated in Fig. 3, the exhaust valve is timed to open at 45° before crank centre on the second revolution of a given cycle, and to close at 8° after the succeeding head centre, as shown in Fig. 4. The inlet valve opens immediately afterward, at 10° past head centre, as shown in Fig. 5, and closes at 42° after the next crank centre, as shown in Fig. 6. These several stages in the cycle are, also, marked on the fly-wheel rim, as is shown. Thus, E is the point of exhaust opening, when at the top of the fly-wheel; O shows the point of exhaust closing, when in the same position; P shows the point of inlet opening, and I, the inlet closure. The figures here given for the points on the arc of the fly-wheel at which the several operations begin are only average or typical, these points varying with different makes of engine, and with conditions involved in design. Thus, in current practice, the point of opening of the exhaust varies, as between types of engines, from 30° to 47° before crank centre, and the point of closing, from 5° to 12° after the succeeding head centre. Similarly, the point of inlet opening varies from 8° to 14° after head centre, and the point of closing between head centre and 40° after.

more nearly square against the valve lift, and so did its work with almost no side friction. Further, since its action was more of a lift than a cross or sweeping stroke, the valve, when once wedged off its seat, was thrown upward with greater rapidity than is commonly the case. This superior action permitted a considerably later opening of the valve, with full escape of the gases before passing dead-center, and seems to be a desirable arrangement. The valve, once lifted, was held full up, until after the piston had passed mid-stroke of its expulsion movement, when it was permitted to close slowly by the easy rounded surface of the cam; closing very slightly after dead-center.

Timing of Valve Operation.—In slow-running engines, closure of the exhaust at dead-center, followed at once

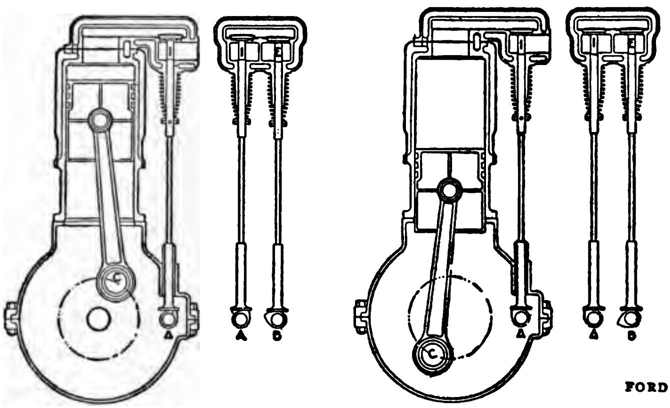
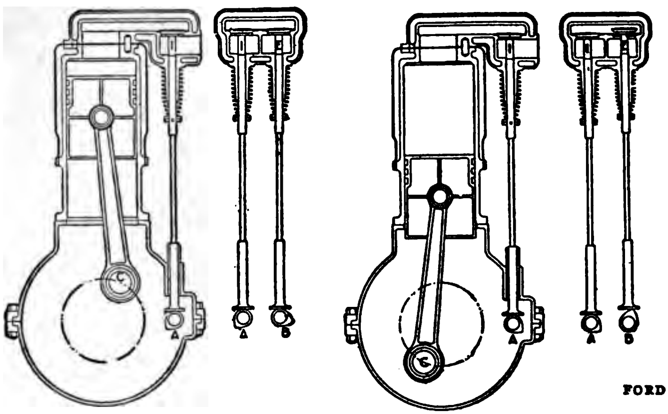


Fig. 15e and 15f.—Sections through the cylinder, piston and valve chambers of a four-cycle engine, showing positions of valves, cams, piston and crank at the beginnings of the intake and compression stages.

by the opening of the inlet valve, is, of course, the proper timing. As the speeds increase, however, there is more or less failure to fully exhaust in the limited time, particularly if the muffler and exhaust pipe are at all constricted, causing back-pressure. In the event of back-pressure, it is evident that the later the exhaust valve closes, the more fully will the exhaust gases have gotten out of the muffler and pipes, and, of course, out of the cylinder. How is there any advantage in holding the inlet valve open beyond the end of the suction stroke, although experience has shown that the incoming charge travels through the supply pipe at a considerable speed, and that, if this pipe is two feet or more in length, the inertia of the incoming charge will continue for a perceptible period, after the end of the suction

stroke, and will ram into the cylinder an appreciable amount more than would be taken in, if the valve closed exactly at dead center.

Valve Movements, Slow and Abrupt.—In considering these poppet valve actions, or any valve action for that matter, it must be remembered that when the valve is nearly closed its effect becomes practically nil, so that closing the valve somewhat after dead center may not be so wide a departure from dead-center closing, as the measurements might seem to indicate. With valves which open more abruptly than do poppet valves, the actual gas movement more closely corresponds to the measured times of opening and closing, on which account the showings of the engine correspond closer to the theoretical calculations.



Figs. 15g and 15h.—Sections through the cylinder, piston and valve chambers of a 4-cycle engine, showing positions of valves, cams, piston and crank at the beginnings of the working and exhaust stages.

Valve Opening and Gas Inertia.—This matter of gas inertia is responsible for some peculiar features, not usually considered in engine theories or treatises. Thus, it is quite common on racing engines to open the inlet at dead-center or close thereto, but not to close the exhaust until the inlet has been opened some 10, 15 or possibly 20 degrees, as measured on the rotation of the crank-shaft. The result of this timing is that the outgoing exhaust gases, usually unimpeded by a muffler, but usually passed through short pipes, create, by their speed through these pipes, a sufficient momentum to continue moving after the pressure in the cylinder has reached atmospheric. This continued motion produces a partial vacuum, into which

the fresh charge rushes, and even passes through the cylinder, and out through these exhaust pipes, under the influence of the momentum of the exhaust gases. This is, of course, a wasteful procedure, so far as fuel is concerned, but it aids cooling, perfectly scavenges the cylinders, and insures, not only a new charge as large as the piston displacement, but also involves that the compression space be filled, as well, with a consequent 20 to 35 per cent more explosive mixture for the succeeding charge. This results in an increase of power.

"Six-Cycle" Valve Timing.—Ordinarily the valves are arranged so as to open and close every second revolution of the crank-shaft, or once in every four strokes of the piston, thus completing the cycle of the engine in four piston strokes. On this account the engine operates on what is known as the 4-stroke cycle, abbreviated usually to 4-cycle. In some few instances, however, where cooling from the inside and scavenging of the exhaust gases is

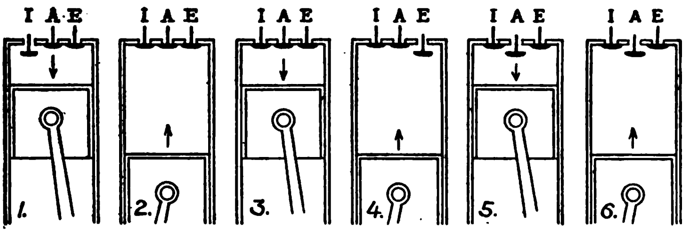


Fig. 15j.—Diagram of a theoretical 6-cycle engine. 1, 2, 3, 4, show the strokes, as in the 4-cycle engine; 5 and 6, the air inlet and expulsion for scavenging the cylinder. I, the inlet valve; E, the exhaust valve; A, the air valve.

desired, it is customary to introduce an idle revolution or two piston strokes, whose purpose is to draw in and expel a charge of fresh air, making the engine a 6-stroke cycle or 6-cycle. In this event the valve arrangement must necessarily be somewhat different, in order to admit and expel the air. The principal difference consists in the addition of a single valve, which opens to the atmosphere, and is operated by a cam on the cam-shaft in addition to the regular cams. In the 6-cycle engine the cam-shaft does not turn at half speed, as in the 4-cycle engine, but at one-third the speed of the crank-shaft: in this way, the inlet and exhaust valves, as used in the 4-cycle engine, are opened at their proper points in the three revolutions composing the cycle. While there is occasional discussion and some experimenting done along this line, the 6-cycle motor is not in common use in automobile work, or in other work for that matter, and need not be further considered here.

Suction Inlet Valves.—Closely connected with the valves are the devices for operating them. The suction-operated valve required no mechanism excepting such as will support it in place. It is usually supplied with a stem in the center of the head, forming a mushroom-shaped piece and having a nut, cotter-pin or head on the end of the stem to limit the motion of the valve. This stem is usually guided in a spider or support, which is concentric with the valve seat in the passage to be closed. A compression spring, usually around the stem, and bearing against the head of the stem, closes this valve. In some cases a tension spring has been used, and this is hooked to the end of the valve stem and to some support on the engine away from the valve. This general description applies to valves of either the flat-seat or conical-seat type.

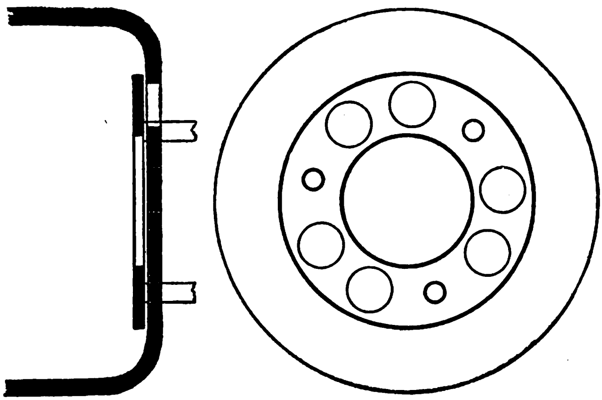


Fig. 15k.—Automatic ring valve; a flat ring with three stems extending through the cylinder head, and closing six openings through which gas is admitted, when suction of the piston pulls down the ring against the tension of springs.

In a suction-operated valve the designer aims to make all parts as light as possible, so that the gases may easily move it open and shut. It may be readily seen that, with a heavy valve, it would be much more difficult to stop and start quickly, because there would be considerable lag, which would act to render its action less perfect than in the case of the lighter valve.

Non-Mushroom Type Valves.—While the mushroom type is the more common in general use, there are some modifications. Thus, the valves used in the Duryea 2-cycle crank-case inlets are thin steel disks, slightly coned, to insure stiffness and to provide, inside the point of the cone, a pocket, or seat for the rounded end of the valve stem.

This valve stem is guided in the usual manner, but is on the inner side of the valve, instead of on the outer side, as is common. On this account it pushes against the valve instead of pulling as do most valve stems. This arrangement is permissible because there is no fire in the crank case, and the stem, with its supporting spider and spring, is not subjected to heat, as would be the case were this construction used in the cylinder of the engine. Since the stem is not fastened to the head but simply presses against it, there is no danger of vibration, due to seating. Thus, all cracks or breaks are avoided, either in the valve or its stem, a trouble frequently found with light valves in high-speed engines. In the Duryea valve, the stem is hollow and con-

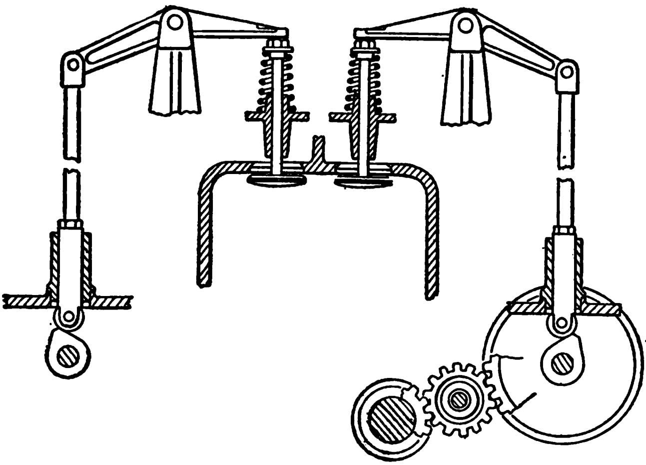


Fig. 151.—Overhead valve lift mechanism. The cams actuate push-rods, which act on the valves through the bell cranks or "walking beams."

tains the spring in this hollow interior, where it is not exposed to any flame, in the event of a back-fire into the crank case. This arrangement insures that the spring will not lose its temper, as it might do if on the outside of the stem, and exposed to even one or two back-fires.

The Automatic "Ring" Valve.—There have been many forms of suction-operated valve used in automobile practice. One form consisted of a ring having several guiding stems, and covering a number of openings placed in a circle under the ring. The advantage of this type of valve is its extremely large area, and the further fact that the incoming gases may escape both inside and outside the flat ring, thus involving that the valve lift need not be large, to insure a very large opening. The difficulty of

keeping these rings tight on all openings alike has been against this form of valve.

General Features of the Mechanical Poppet Valve.—In the mechanically-operated valve, it is common to extend the stem of the valve toward the crank case, and to provide a spring around the stem, which holds it firmly on the valve seat. Its opening is achieved by some sort of push-rod, or valve lift, operated by a cam on a shaft near the crank-shaft, which turns at half the crank-shaft speed, by means of a small gear on the crank-shaft, which engages a double-sized gear on the cam-shaft. This arrangement is

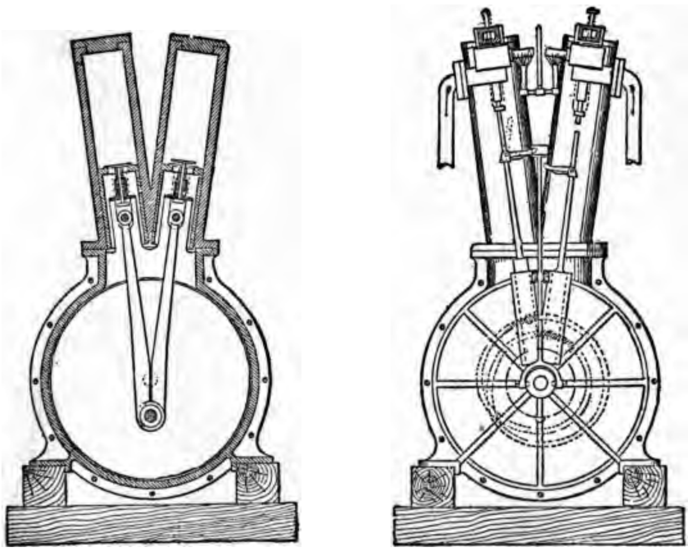


Fig. 15m.—Side elevation and sectional diagram of the Daimler, two-cylinder V-shaped engine; showing annular cam-groove, for operating the exhaust valves and piston-head air valves; also position of the pistons, pitmans, and crank at lower dead centre.

the most simple, although not always considered the most acceptable. Modern practice seems to be tending toward placing both valves in a single port, set on one side of the cylinder, with their stems projecting toward a common cam-shaft, on which are suitable cams to operate first one valve and then the other.

Size of the Valves.—It is now common practice to make both valves of the same diameter, duplicates of each other largely for sake of simplicity in manufacture. Although earlier makers used smaller inlet valves, on the theory that

the cold gases require less area to enter than do the hot gases to exhaust, the present view is that the cold gases enter under but slight pressure (*i. e.*, the difference between the partial vacuum in the cylinder and the atmospheric pressure outside), whereas the exhaust gases pass out at a considerable pressure (from 20 to 40 pounds, or even more, at the beginning, and decreasing toward atmospheric, at the end of the exhaust stroke). On this account no such

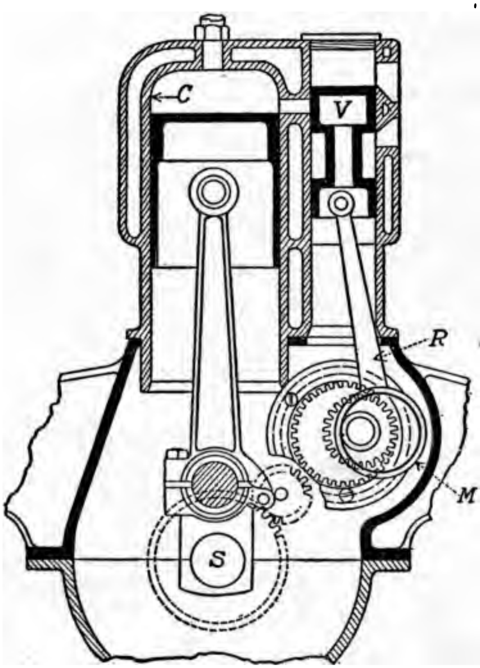


Fig. 15n.—Section of a type of engine having a reciprocating piston valve operated by an eccentric on the second shaft. C is the cylinder wall; V, the piston valve; R, the valve rod; M, the eccentric; S, the crank-shaft. With the valve at the bottom of its stroke the exhaust is open; at the top the inlet is open.

large opening is needed, and in high-speed engines, there is often found a considerable difference in size, the inlet valve being much larger than the exhaust. This is particularly true in French racing engines, where speeds of *from 3,000 up* to 5,000 turns per minute have been proven *quite possible.*

Overhead Valve Lifts.—A number of designers have given preference to the type of cylinder having valves in the heads, and, naturally, having their stems projecting away from the crank-shaft, either parallel to the cylinder axis, or at some angle, in a few cases, at a right angle thereto. In these forms the usual push-rod, or valve-lift, must be combined with some form of rocker-arm. The more common arrangement is to provide pivots for these rocker-arms above the engine-head, and to lengthen the push-rod to lift one end of the rocker-arm, while the other depresses the valve stem, forcing it toward the cylinder center and thus opening the valve. The leading objections to such overhead construction are (*a*) the difficulty of lubrication, (*b*) the complicated appearance given the engine and (*c*) the noise likely to arise from these working joints. In a few instances, with the valve stems at right angles to the cylinder axis, the rocker-arms have been pivoted in, or near, the crank case, and simply one end being extended up to the valve stem, the other being operated by the cam on the cam-shaft. This construction is slightly simpler than the rocker-arm and push-rod type, but it is also heavier, and, therefore, has not found great favor. In some instances the overhead valves are operated by an overhead cam-shaft, driven either by a vertical shaft at one end having two pairs of bevel gears, or by chain, or even by a train of spur gears. The objections of noise and complexity, with more difficult lubrication, have militated against this form, although it is not uncommon.

The Common Cam-Shaft.—There have been many forms of valve-operating devices, but the common cam-shaft, usually located in or adjacent to the crank case, is used so fully, to the exclusion of other devices, that such need hardly be mentioned. This is particularly true because the automobile engine is usually built with more than one cylinder, and a valve-operating shaft, extending from one cylinder to the next, serves to operate the valves of all cylinders, instead of using separate operating devices.

Daimler Double-Groove Valve Lift.—It may be interesting to note, however, that some very simple valve-operating arrangements have been employed. Thus one of the early Daimler single-cylinder engines used, for its exhaust valve-lifting device, a groove cut in the disk face of the fly wheel, this groove being substantially two concentric circles for part of their length but on the other part joined and crossed much as though a figure "g" had been formed with one quite large end, which was looped down to encircle the smaller end. Into this groove was projected one end of the valve push-rod, which was provided with a shuttle, or lengthened shoe, arranged to follow the groove rather loosely. This shuttle, being of some length, necessarily continued moving across the intersecting point of the grooves, so that, after traversing the small, nearly circular track, it next traversed

the larger one and then returned to the small one, as will be seen by reference to the diagram. It will also be seen that, when traversing the larger curve, the valve-lift would be farther from the crank-shaft than when traversing the smaller one. Many modifications of this simple arrangement have been applied to gas engines with more or less success, but virtually all of them have been abandoned for the simple cam arrangement.

Other Valve-Operating Mechanisms.—Another simple device, employing no gears, was produced by fitting an eccentric on the crank-shaft, one end of the valve-lifting rod being attached to its other end traveling in a specially-shaped slot, which performed the same duty, so far as the free end of the rod was concerned, as did the Daimler grooves. Thus, on one stroke of the eccentric the push-rod lifted the exhaust valve, but, on the next stroke it had traveled to one side, and entered a groove leading away from the valve so as to miss it. But at the end of this stroke, again, it dropped into another groove, which carried it back to the first groove, these desired results being obtained by making the end of each groove slightly higher than the beginning of its successor. Still another device employed a ratchet wheel mounted on a slide operated by an eccentric. At each movement of the slide, corresponding to one-half revolution of the crank-shaft, the wheel would be lifted and on the next movement, corresponding to the next half revolution of the crank-shaft, it would be depressed and turned one ratchet notch. In this wheel were a number of holes corresponding to every second ratchet notch, so that on one lifting stroke the valve stem would be raised, but, on the next, the hole in the wheel would slip over the end of the valve stem without lifting it.

Troubles With Valve Mechanisms.—Probably no problem connected with the gas engine has received so much thought as the operation of the valves. Valves have always been recognized as a disagreeable necessity, and numerous inventors have attempted to eliminate them. A more or less constant round of experiments and improvements has been the result of their work. The slide valve, copied from the steam engine, was one of the first forms in use, the poppet valve coming much later; while the sleeve valve, the piston valve, the rotary valve, and many other more or less promising forms, are of later development. There is great likelihood that, in the automobile business, as in the boat business, the valveless, 2-cycle engine will finally win the leading place, simply because it avoids these many valves and their mechanism; being not only reliable because it lacks these troublesome parts, but is also cheap to build, and easy to assemble and adjust, for the same reason.

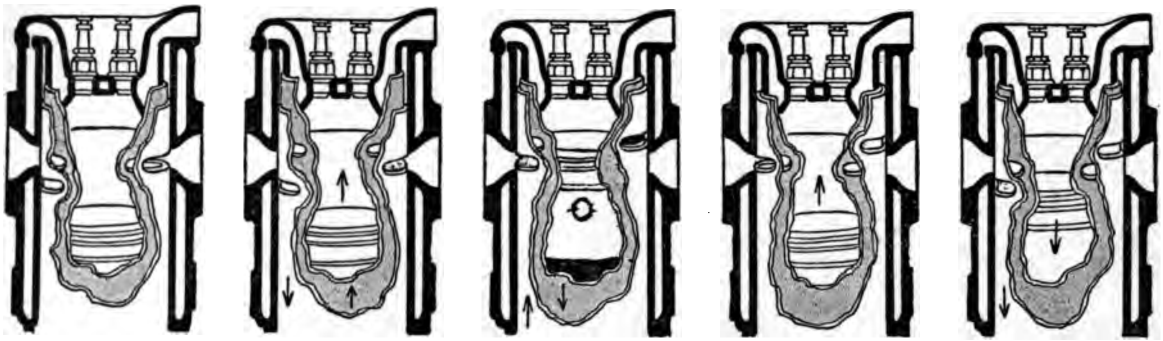
CHAPTER XVI.

NON-POPPET VALVES.

Varieties of Non-Poppet Valves.—While the poppet valve has been the recognized gas engine valve ever since automobile work attained any prominence, there has recently come into the field a number of new types. In some respects these are modifications of the old slide valve, although hardly recognizable in their new forms. Roughly speaking, they are of five general types, as follows: (1) sleeve valves, (2) rotary valves (sometimes called cylinder valves), (3) ring valves, (4) piston valves and (5) disk valves, which although they revolve, are of disk, rather than cylindric, shape.

Reasons for Seeking New Valve Types.—While all of these valves are not new, having been proposed and tried time and again, ever since the gas engine existed, they have come into prominence in recent years for several reasons. The poppet valve serves well, when made in small sizes, because then it can be light, is not likely to warp, is easily ground to a seat, and is not difficult to lift nor likely to be noisy. But as engines became faster, the difficulty of lifting the poppet valve quickly enough, and allowing it to close rapidly, without noise, taxed inventive ability. To get the charge in and out swiftly involved that it be of large size, with almost entire certainty of warping, and with much-increased difficulty of lifting, not to mention the fact that the ports, or valve pockets, become exceedingly large.

The Knight Sleeve Valve.—Some years ago an American inventor named Knight, brought out the "Silent Knight" engine; having sleeve valves, or rather valves formed by openings in two concentric sleeves, which were placed between the piston and the cylinder wall. This engine was shown at the automobile shows, particularly at Chicago; was described in the magazines, and was generally exploited, with little or no success. Finally Mr. Knight took it abroad, where it was taken up by the English Daimler Company, who devel-



A B C D E

Fig. 16a.—Diagrams showing the operation of the sleeves in the Knight two-sleeve-valve engine. A shows the position of the sleeves at the point of inlet. The inner sleeve is on its way upward, the outer sleeve near to the end of its downward travel. B shows the conditions at the beginning of the compression stroke. The outer sleeve is at the end of its down-stroke, the inner near the end of its up-stroke. C shows the conditions at the beginning of the firing stroke. Here the port in the outside sleeve nearly registers with the exhaust port in the cylinder, while the opposite ports in both sleeves come to register above the inlet port; the outside sleeve traveling upward, the inside sleeve, downward. D shows the general position at point of exhaust, where, as may be seen by comparison with the previous figure, the inside sleeve is again on the downward travel, while the outside sleeve is at about the limit of its up-stroke. E shows the movements after the exhaust, and before the next inlet. Here, as may be seen, the ports in the inside sleeve are nearly in inlet position, while the outer sleeve is traveling down to complete the opening.

oped it more fully, made it more perfectly, and finally submitted it to the Royal Automobile Club Testing Committee. By this committee it was put through a severe test, followed by severe operation on the road, which tests it met in a perfect manner. This advertising, and the results shown in these tests, came before the public at a time when something of this sort was needed by the market, and, as a result, a number of foreign makers, and several Americans, took up the Knight engine, and have since been supplying cars using this type. The result was an immediate stimulation of inventors in their attempts to produce better valves than had before been offered, and some of these will be described in the following pages.

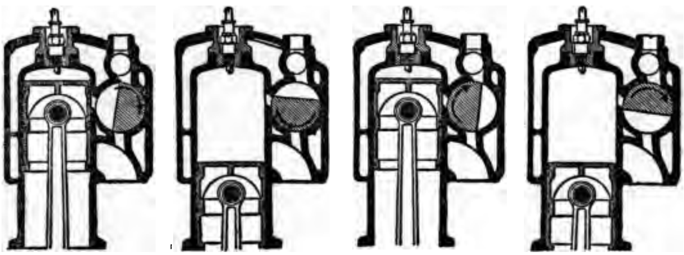
The Knight Valve Described.—In the Knight sleeve valve two concentric sleeves are provided, which have ears or lugs at one side of their lower ends. To these lugs short connecting rods attach, extending to the eccentric shaft, which takes the place of the ordinary cam-shaft. By means of these eccentrics, these two sleeves are moved a short distance lengthwise the cylinder, not together, but one slightly ahead of the other. Ports are cut through these sleeves and through the cylinder walls to admit and exhaust the gases, the inlet being on one side of the cylinder, the outlet on the other. Into the upper end of the cylinder a head projects, which is small enough to fit into the cylindric sleeves forming the valves, and is provided with packing, rings to hold the pressure, much as the piston is provided.

Movement of the Sleeves.—Since the sleeves do not move a great distance, their motion is necessarily slow, and the high speed and quick action of this engine is not due to a rapid opening of the valve passage, so much as to the fact that the passage, when opened, is both large and straight. While the amount of valve movement may be more or less as the designer may wish, a 5½-inch-stroke motor has a valve movement of 1⅛-inch stroke. From this fact it may be seen that the friction of the valve motion is not excessive, because this movement, in the time required to make two crank-shaft revolutions, is extremely slow. It is estimated that, at 1,000 revolutions per minute, a motor of this stroke would have a piston speed of 916 feet per minute, while the sleeve travel would be less than 94 feet. On account of this slight movement, the sleeve lubrication is not a difficult matter.

Other Sleeve Valves.—Perhaps the greatest variety is to be found in the sleeve valve class, in which the Knight is practically the only exponent of the double-sleeve form, single-sleeve forms being offered by a number of makers and the rotating as distinguished from reciprocating single-sleeve being offered by others. There is also the Argyll sleeve valve, which is both rotative and reciprocating.

Construction of the Sleeves.—These sleeves, like the piston and cylinder, are made of gray iron. They are, approximately, 5/32-inch thick, and are finished by grinding, inside and out, and provided with an enlarged portion or ring at the lower end, which prevents distortion by the connecting rod lug forming part of the ring. The slots, or ports, cut in such a valve, used on a motor of 4¼ bore are ½ inch high for the intake and ⅝ inch high for the exhaust, and in each case extend 124 degrees around the cylinder wall. This length gives approximately 4½ inches in length of opening by ½ inch high, or a total of 2¼ square inches for the inlet and nearly 3 square inches for the exhaust. This large area permits the high power and high speed of this engine, and is all the more efficient, because, as before stated, the opening is a free, straight passage.

Operation of the Sleeves.—The two sleeves do not reciprocate in unison, but one about 70 degrees ahead of



A B C D

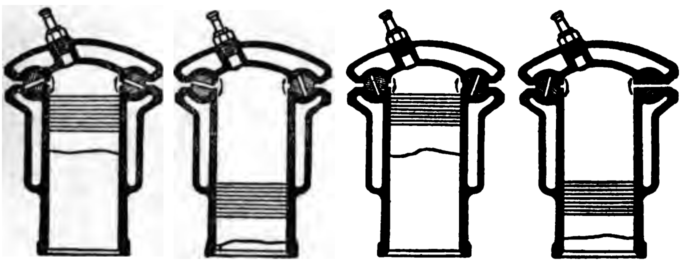
Fig. 16b.—The Darracq rotating cylinder valve, showing position of the notched cylinder at the beginning A, of the inlet stroke; B, of the compression stroke; C, of the working stroke; D, of the exhaust stroke.

the other. On this account there are times when both sleeves are moving in the same direction, and again when one is going up while the other down. This action is provided to secure a more rapid opening and closing of the exhaust, combined with short movement of the sleeves. The intake port is opened early and closed late, so as to insure ample filling of the cylinder, the total time from opening to closing being 220 degrees, usually from top dead-center to 40 degrees after bottom dead-center, and, because of the quick opening effect it is said to get 50% open in 20% of the total time. It remains at the maximum opening point 15 degrees while the closing is not so abrupt.

Difficulty of Lubrication.—One of the objections urged against the Knight engine is the difficulty of lubrication because the hot gases pass through these sleeves, which must be oiled. There is no doubt but that this heat tends to destroy the oil at the exhaust openings, but the mass of the

sleeve is so large that the heat is carried away before serious damage is done. Further, the engine is water-jacketed, and the motion of the sleeves brings the hot parts against the cool wall, where the heat is quickly carried away.

Difficulty of Cooling.—Another objection is the obstructed path over which the heat from the piston must travel to escape. Everyone knows that the center of the piston is the hardest part in a gas engine to cool. The heat at the center of the head must pass to the piston walls, then, through an oil film, to the surrounding surface. In the usual engine, this surface is the cylinder wall, kept cool by outside cooling, but in the Knight engine this surface is one of the valve sleeves, after which the heat must pass another oil film and another sleeve before it reaches the final oil film and the cylinder wall. Undoubtedly this objection is well taken, but, since these engines are water-cooled, there is evidently sufficient cooling efficiency to retain operative conditions.

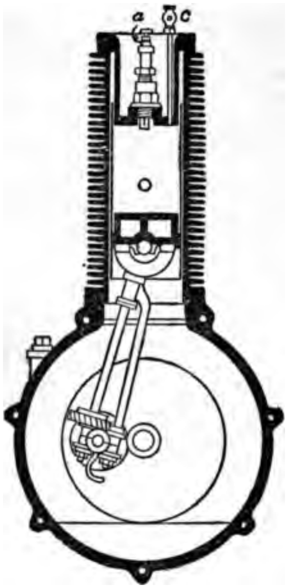


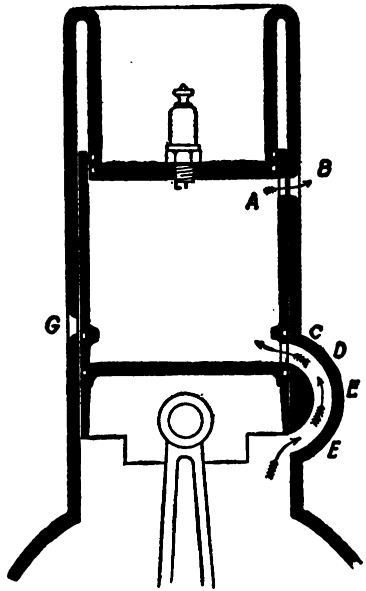
A B C D

Fig. 16c.—The Mead rotating cylinder valve, showing positions of perforated cylinders at A, beginning of intake stroke; B, end of intake stroke; C, beginning of working stroke; D, beginning of exhaust stroke.

Unequal Expansion.—A further objection, as doubtless found by the makers more or less often, arises from the fact that different irons do not expand and contract alike, but with this point the user is not particularly interested because engines which pass the makers' inspection are probably right in this particular.

Rotary Sleeve Valves.—The rotary sleeve is in effect a cylinder valve except that instead of being placed in a separate pocket it is placed between the piston and the cylinder wall. It is best known in France, where one or more examples are found, and consists of a full length sleeve rotating in one direction at half the number of turns of the crankshaft. A single port in the upper end of this sleeve serves for both intake and exhaust, the cylinder wall having two parts, with which this single port registers at the proper time. These two ports are not opposite, as in the Knight, but are





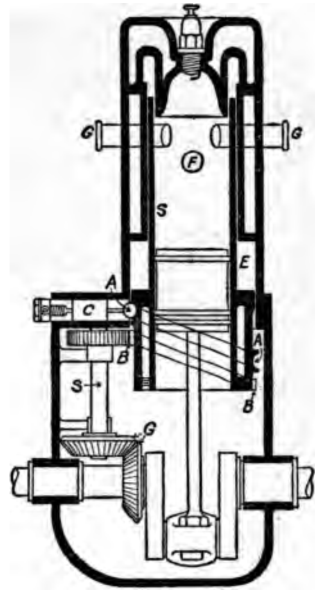
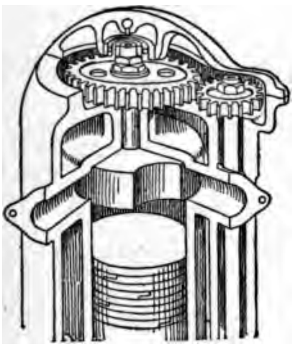


Fig. 16d.—The Dawson engine, an early example of the sleeve valve principle. The valves are in the side of the cylinder. The piston carries a sleeve extension upward, as shown, and is rotated by skew gears working from the crank. Spark plug at a; relief cock at c.

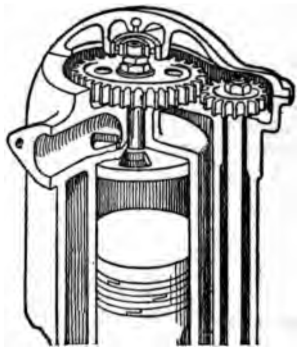
Fig. 16e.—A three-port 2-cycle sleeve engine. The piston has an upward sleeve extension which on down-stroke opens

placed at approximately 90 degrees apart, so that there is a considerable space following the closing of the intake port, during which space and period of movement, the compression and working strokes take place.

Operation of the Rotary Sleeve.—This rotating sleeve is driven through a gear at its lower end, the gear train being enclosed in the crank-case, where all parts may be well oiled and kept free from dirt. These gears may be spurs, or may be of the spiral type. Some provision, such as a row of balls, is necessary to support the sleeve, and prevent it from being moved by the friction of the piston. To insure better packing and less danger of escape of gases, a very wide ring is fitted to the exterior of this sleeve and pinned in position so



16g.



16h.

Fig. 16g.—The "Cid" rotary ring valve, showing method of opening the ports through slot cut in one face.
Fig. 16h.—The Reynolds rotary disc valve, showing method of opening the ports through a perforation in the thickness of the disc.

that it rotates with the sleeve. Being outside of the sleeve, it is not heated directly by the burning gases, and, because of its elasticity, it maintains compression just as do ordinary piston rings.

The Sphinx Ring Valve.—Much resembling the packing ring of this exterior sleeve type is the ring valve used in the Sphinx engine, which is, in reality, a short sleeve placed above the piston, being split, so as to be elastic, thus permitting it to hug the cylinder walls and make gas-tight joints. This ring is moved a short distance up and down the cylinder wall by a rocker-arm, which is pushed downward by a plunger and spring and thrown upward by a cam on a cam-shaft. The point of the rocker-arm engages a pocket in the inner side of the *ring next the* firing chamber. This cam-shaft, *rocker-arm and plunger* with spring are close analogues of

similar parts used to operate an overhead poppet valve, but the ring valve does not stop against a seat, does not operate without oil and requires no valve pockets or cages. On one side of the cylinder wall are two ports, the inlet and the exhaust. When the valve is lowered, the intake opening comes into service and when raised the intake closes and later the exhaust opens.

Resemblance to Poppet Action.—Like the poppet valve, these motions are not regularly spaced, but are controlled by the cam and spring, so that the opening of the intake follows the closing of the exhaust almost immediately. In other words, downward motion of the valve is quite rapid, while the upward motion is much slower and it is during this slow movement that the pressure of the compression and working strokes occur.

The Cid Ring Valve.—The Cid ring valve is of the rotary type, although very much like Sphinx in size and width. In this, as in the rotary-sleeve type, a single opening passes in front of the ports, one after the other at the proper distance apart and in the proper time. This valve is driven by a central shaft projecting through the head of the motor, on top of which is a pair of gears through which motion is received. The opening in the valve is commonly made as a large slot, and the valve, having some elasticity, like a piston ring, maintains a firm seat against the cylinder wall, making a gas-tight closure of the ports, when they are not supposed to be open. The driving shaft, or spindle, is made gas-tight by being fitted into a conical seat, upon which it is held by pressure of a spring.

The Duryea Cylinder Valve.—The cylinder valve, more commonly termed the rotary valve, is represented by a goodly number of examples. One of the first of these to be shown in automobile service is the Duryea, first applied regularly to automobiles in 1906, and shown at the New York Show of 1907. This consists simply of an enlarged shaft, which takes the place of the cam-shaft but is located well up to the heads of the cylinders and driven by silent chain, instead of by gears, in the manner now common. This single shaft has a small portion cut away at each cylinder port, so as to form a gas passage and the opening in which the shaft is placed has three cross openings; the first leading from the shaft to the cylinder; the second, to the inlet pipe and the third, to the exhaust pipe.

Operation of the Duryea Valve.—When the cut-away portion of this cylindric valve lies between the inlet opening and the cylinder port, the new charge may enter. Rotation of the valve closes the cylinder port during the compression and working strokes. The inlet and exhaust openings, however, are not equidistant, from each other and from the cyl-

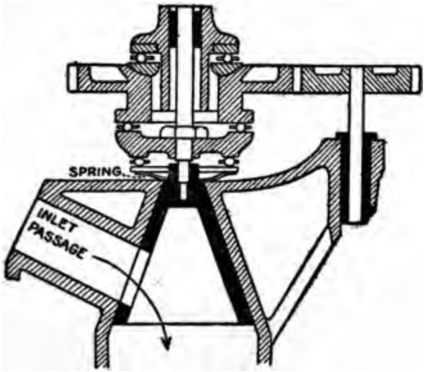


Fig. 16j.—Coned rotary ring valve in cylinder head. Such valves may be single for both ports, double, side by side, one for each port, or nested, one within the other, acting differentially like a double-sleeve valve.

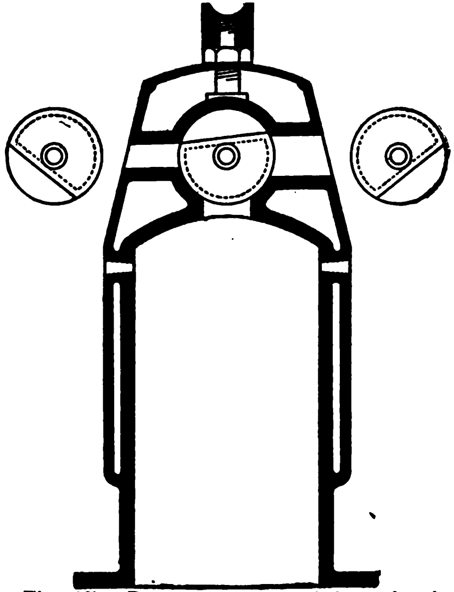


Fig. 16k.—Duryea rotating cylinder valve in cylinder head, showing inlet, closed and exhaust positions.

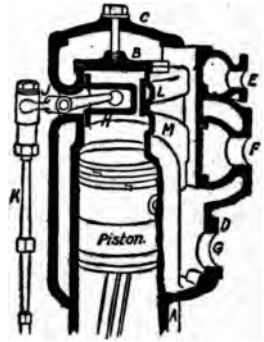


Fig. 16l.—Diagram of the Sphinx sliding ring valve. The ring H, slid up and down by the bell crank J, opens and closes the inlet L E and exhaust M F.

inder port, but more nearly 90 degrees from the cylinder port, and, therefore, nearly 180 degrees apart. Because of this spacing, the rotation of the valve does not open communication between the inlet and the exhaust, but, at the close of the working stroke, or slightly prior thereto, this valve passage opens a way between the cylinder port and the exhaust, allowing the gases to escape. In this valve, as in the Knight and many others of these modern types, a virtually straight passage exists, both for inlet and exhaust. While the height of the opening need not be great, its length is considerable, with the result that the gases enter and leave quickly, and the engine is able to attain high. speeds. Its action resembles that of a steam engine in its noiselessness and its ability to accelerate quickly.

The Darracq Cylinder Valve.—The Darracq cylinder valve is almost a copy of the Duryea, the principal difference being that the cylinder port is located somewhat lower than in the Duryea. In both types the cylinder port is usually placed on the cylinder sides, although a number of Duryea engines have been built with the valve across the cylinder tops. The side placing presents the advantage that each stroke of the piston pushes more or less oil from the cylinder walls into the valve port, thus lubricating and packing the valve so as to insure gas-tightness. In the Darracq the cylinder port is so low down that the piston passes it, and rises above it, at the time of greatest compression and at ignition. The object of this placing is to relieve the valve from the extreme pressure generated at the time of ignition, but, since a very slight movement downward opens the port, this advantage would seem to be more theoretical than practical. On the other hand, this location of the cylinder port does not permit full exhaustion of the burned gases because there is still some piston movement after the port is closed on the upward stroke. While it is not certain that this amount of displacement greatly affects the action of the engine, there is some loss of fuel-burning capacity and some slight negative work.

Advantages of the Rotary Valve.—The great advantage of this type of valve is the fact that, being fitted to a port having a length practically the whole diameter of the cylinder, it opens a large area quickly although moving slowly, and thus permits high speeds. To obtain the best results, these valves should be of fairly large diameter, the Darracq being approximately two-thirds the diameter of the cylinder, while the Duryea was considerably smaller, being practically from two-fifths to one-half. The Duryea depended upon its supporting bushings for its bearing support, but the Darracq is fitted with large annular ball-bearings at the two ends. The amount of pressure against such a valve is extremely slight, as compared with the amount against the piston head, which is transferred by the connecting rod to the crank-shaft

bearings. Further, the crank-shaft moves at twice the angular velocity of this form of valve, and does not have nearly so large a bearing surface. As a result of these conditions, these bearings are seen to have a very long life and little loss from friction.

Construction of Rotary Valves.—As thus described, rotary valves are but single shafts, but the Duryea has also been built in sections, one to each cylinder. Each of these sections are slightly tapered and provided with adjusting nuts, by which they could be set into the tapered seats, as tightly as desired. Each section drives the one adjoining it through an Oldham coupling, or similar joint, which arrangement renders the valve free from any warping or distortion of the cylinder in service. Experiments have shown that, although the engine is run without lubrication, until pistons stick in the cylinders, the valves remain lubricated and in perfect order. The water jackets of the engine extend well around these valves and in the Duryea the valve was made hollow, with water circulating through it for still better cooling.

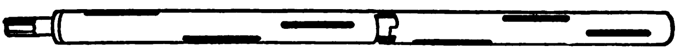


Fig. 16m.—The Mead rotating cylinder valve for a six-cylinder engine.

The Mead Rotary Valve.—In the Mead rotary valve, the construction is somewhat simpler, but two valves instead of one are used. These are placed on opposite sides of the cylinders, the one serving for the inlet, the other, for the exhaust. Instead of having a passage acting from one side, as in the Duryea and Darracq just described, the passage is directly diametric. It is believed that this type of passage offers more opportunity to heat and expand the valve than if on one side only, but this type of passage permits driving the valves at a quarter the crank-shaft speed, because the gases pass alternately through said passage, which would not be the case, were the passage cut at one side instead of directly across the center of the valve cylinder. In a cylinder of 4-inch bore by 4½-inch stroke, the exhaust slot in the valve for each cylinder was 3¾ inches long by $\frac{7}{16}$ wide, giving an area of 1.6 square inches, the inlet opening being the same length but $\frac{4}{16}$ high, with an area of .86 square inch.

Operation of the Mead Valve.—The intake opening starts ten degrees after the head dead-center and remains open until forty degrees past the crank, or bottom dead-center. The exhaust opens 73 degrees before crank dead-center and closes very closely or slightly after the head dead-center. These valves are made with a clearance of .0315 inch, where the valve bearings are and .002 inch at the point where the slots are cut. Each valve of the Mead is lubricated at five

points by oil cups and oil grooves are cut in the valve. In the Duryea 5-inch bore and stroke engine, the port length was about four inches, with an opening of ⅝ inch, giving an area of 2½ square inches, the same being used for both inlet and exhaust. All these valves are placed close to the cylinder bore, with, consequently, almost no cylinder port wall exposed to the flame of combustion, an effect which adds some efficiency and lessens need for cooling.

The Itala Cylinder Valve.—The Itala cylinder valve is also of the rotary type, but, unlike the three just described, the valve lies parallel to the cylinder axes instead of at right angles to it, and there is one valve for each pair of cylinders. This valve rotates at one-fourth crank-shaft speed, and is provided on opposite sides with openings, which permit this slight rotative speed. These valves, of which there are two for a four-cylinder motor, are driven by helical gears from a half-time shaft and each valve is nearly as large as the cylinder bore. Thus, in a motor of 105 millimetres, the valve cylinder is 100 millimetres. The seeming objection to this valve is that the ports lie lengthwise the cylinder walls instead of crosswise, but since the piston is down at the time of exhaust opening, this position is not objectionable. A single port into the cylinder serves, just as with the other cylindric valves. In this valve cylinder the intake and exhaust ports have no communication with each other, the intake passages being placed in the lower end of the valve, while the exhaust gas passes away at the upper end, there being a clear passage at both ends of the valve into which these openings discharge.

Success of Rotating Valves.—These various valves and the successes attained by them indicate that there is no difficulty in making a revolving gas-tight joint in a gas engine when modern machine methods and modern mechanics are available. The failures of early mechanics, in their attempts to make suitable revolving steam engine valves, was not due to the type of valve so much as to the fact that these parts could not be properly fitted. A slide valve could be scraped into place, and, if not perfect, would wear down, until, in time, it became perfect, but a rotary valve must fit the passage in which it is mounted, and this involves both a perfect hole and a perfect cylinder, which can only be produced by modern methods, such as grinding.

CHAPTER XVII.

Gas Engine Operation.

Elements of Piston Operation.—The limiting factor in an automobile engine is not the ability of the gas to flow into, or out of the cylinder, for gases under pressure act with surprising rapidity. It is rather the friction of the piston and its rings against the walls of the cylinder. While extremely high speeds may be secured during tests or similar trials, it is generally recognized that an engine, to be durable and economical, must not be operated at piston speeds very much beyond those established as safe and successful by usage.

Side-Thrust of the Piston.—There is much misconception in this matter of piston speed and piston friction. Thus, the stock argument against the use of the horizontal engine is that the friction of the piston against the lower wall of the cylinder tends to wear it out. This claim is wholly unfounded, because the weight of a modern automobile engine piston is so slight, as compared with its side-thrust against the wall, due to the angularity of the connecting rod, that it may be practically ignored. Therefore, if the engine is kept clean, the amount of wear on the lower side of a horizontal cylinder, due to the weight, is wholly negligible.

Power Thrust of the Piston.—This same principle, however, does not apply to the side thrust of the piston, which is produced wholly by the pressure against the piston head, working against the angularity of the connecting rod. When it is remembered that the average working pressure in the cylinder rises from 200 to 400 pounds, on the working stroke, and from atmosphere to 40, 80 or 100 pounds, on the compression stroke, on each square inch of surface, it may be understood that an automobile piston of the usual diameter receives a pressure amounting to a ton or more at each impulse, when the engine is working hard. If, therefore, the

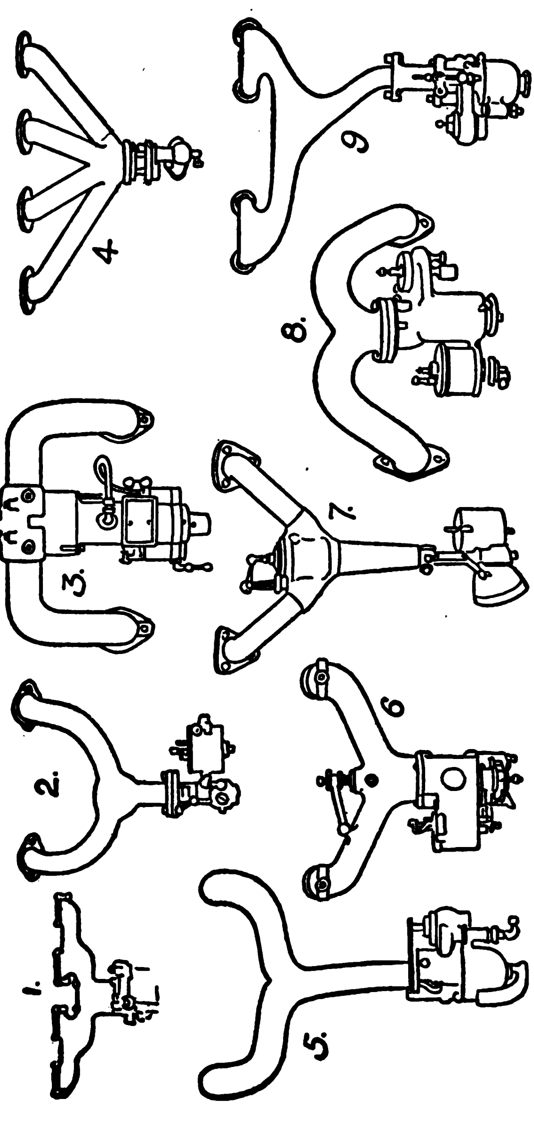


Fig. 17a.—Various types of inlet manifolds. Nos. 1, 4, and 9 are arranged for four-cylinder engines having separate inlet ports for each cylinder; the others are for engines having the inlet chambers of each two contiguous cylinders in common. The shape of the inlet system is an important consideration in engine operation: the problem being to get a direct, equal length of path to all cylinders, and to avoid bends, which create power losses by friction and resistance, greatly in excess of the total length of piping involved.

inclination of the rod is but one-fifth of its length, the pressure against the side of the cylinder is, generally speaking, about one-fifth the total pressure on the head. The saving feature is that this pressure is not of long duration, and rapidly grows less during the power stroke, also that it is not repeated until ample time has been allowed to get oil upon the working surfaces. A slight consideration of these pressures, as illustrated by diagram, shows the necessity of proper and generous lubrication for the pistons of the motor vehicle engine, and explains why some substance like graphite, which may remain in position between the two metal surfaces, is decidedly valuable. Just as a slow-running bearing may be heavily loaded, but a fast-running bearing should be as lightly loaded as possible, so in engine practice the piston speed should not be excessive, because of this heavy loading to which the head of the piston is exposed.

Limitations of Piston Speeds.—In stationary gas engines piston speeds of between 600 and 750 feet per minute are considered high enough for good results, but in motor-vehicle practice far higher speeds are employed, partly because extreme durability is not expected for the vehicle, or any of its parts, and partly because high power with light weight demands a higher working limit. On this account it is quite common to figure automobile piston speeds at 1,000 feet per minute, although it is probable that, under usual working conditions, they are much below this, usually not above 750 feet per minute. Although some engines are able to maintain much higher speeds, it is not the general practice.

Piston Speeds and Engine Design.—Since the piston speed is the limiting factor, it is evident that the remainder of the engine should be designed with this feature in mind, and as the basic thought. Having determined the piston speed at which the engine shall normally work, the designer may then determine the crank-shaft speed, also the strength and size of the various parts. It is quite evident that, with a given piston speed, the crank-shaft speed varies as the length of the stroke; more revolutions being necessary, or possible, with a short-stroke than with a long one. This increased number of revolutions is advantageous from the point of view of any designer, who believes that speed variations should be made by throttling the engine rather than by the transmission gear. In this connection it may be said that two schools of designers exist. The one school, like most of the early foreign inventors, believes that the engine, for the sake of economy, should be run at a fixed speed, and that all, or virtually all, variations in speed should be secured by means of the speed-changing device. The other school, representing the now widely accepted practice, originated by Duryea in America, believes that the gasoline engine should approach as closely as possible to *the beautiful flexibility of steam* engines or electric motors, and should

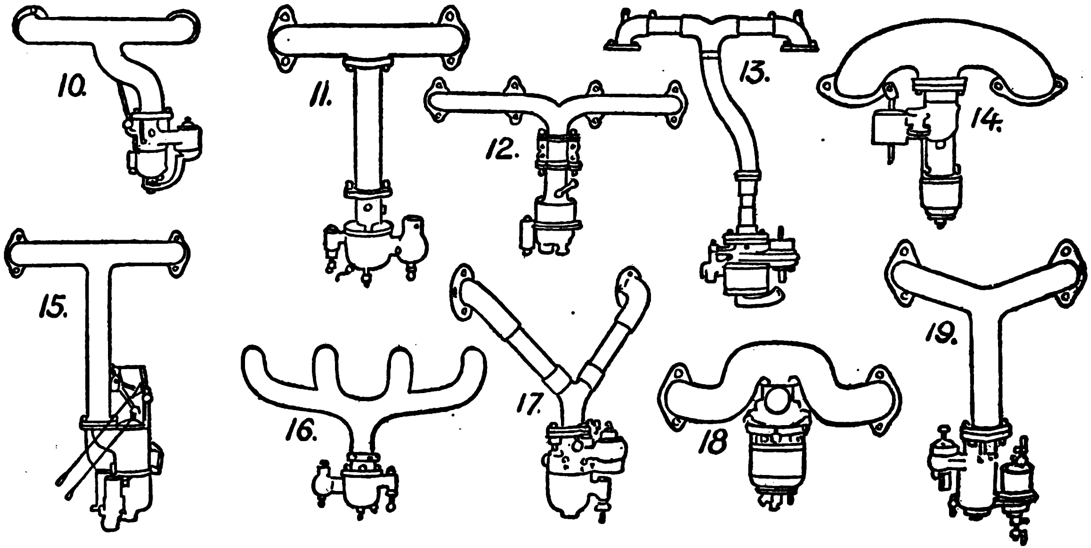


Fig. 17b.—As in the previous figure, these manifolds show proper forms for two types of inlet chamber in the cylinders; the four-port, for separately cast cylinders, and the two-port, for block-cast pairs. Nos. 12 and 16 are of the former type. Even with shapes of inlet manifolds closely alike, there is considerable difference in efficiency, as it is desirable to make the paths to all cylinders of the same mechanical length, in order to avoid over-feeding of one pair, as against under-feeding of the other. In general, all bends are to be discouraged, and straight lines preferred.

thus be capable of delivering an extremely wide range of speed and power.

Variable-Speed Engines.—While the operation of the variable-speed engine may not be as economical throughout its entire speed range, as would a less flexible engine employing more gear-changing devices, yet, below the maximum, it is probable that the variation in economy is not great enough to be serious. Most users also prefer a slightly lower economy to the constant labor of changing gears, or, rather, to the constant speed at which the car is forced over good roads and bad, generally to its detriment, by the driver who is too negligent or careless to change gears when a rough spot or bad road comes in sight. Every observer has noted the "recklessness" of the average automobile driver, but not everyone understands that this is too often due to the fact that the engine will not throttle down and pick up perfectly and quickly at the will of the driver, but must be kept pulling at a high speed, if it is to take the vehicle surely and safely over the bad road or rough spot, without change of gears.

Engine Speeds and Road Conditions.—A full consideration of these facts indicates that there are two classes of users who are largely the products of two classes of road conditions. The operator desiring the flexible engine with few gear changes is the one who is obliged to traverse a widely irregular quality of road. On the other hand, the driver preferring many changes of gear is one who is accustomed to driving at a high speed for long stretches, and prefers an extra speed in his transmission box, so that he may save his engine needless racing while driving the car at the desired rate. The man driving over mixed or bad roads does not find himself able to use high vehicle speed for long stretches, and, consequently, has less objection to speeding up the engine to meet the temporary needs. Further, the good-roads driver has less occasion to slow down, and so does not need great flexibility of engine as often as the driver in the bad-roads locality. That the flexibility of the steam engine or electric motor is an indispensable condition to the modern designer can hardly be denied; and the short-stroke engine, having a wide range of speeds, for example from 200 to 2,000, or from 4 to 40 miles an hour, is the form to be preferred.

Working Pressures and the Weight of Parts.—In considering the relative proportions of bore and stroke, it is often urged that the long-stroke engine with a small piston, not having the weight of piston and connecting rod to reciprocate, therefore involves less strain and friction in the bearings, but this claim is not borne out by the facts. While it is true that the small piston weighs less, it is also true that the long connecting rod weighs more, since, being exposed to a much higher transverse speed, even with the same piston

speed, it must be made considerably stiffer, because of its length. Furthermore, most motor-vehicle engines are of the multiple-cylinder variety, and, for the sake of compactness, have their cylinders placed close together, with the result that the small-bore, long-stroke engine does not have such short and stiff length of crank-shaft as the large-bore engine, and cannot have such long and serviceable bearings. Some makers attempt to overcome this by the use of ball or roller-bearings, but for motor practice, where the strains are heavy but intermittent, it is believed by most designers that the plain bearing is not to be excelled, and, if of ample length, as it can be in a motor of large bore, it gives perfect satisfaction. This claim of wear on the bearings, like the one of piston friction against the cylinder wall, is greatly exaggerated, because the pressure of the working charge against the bearing is much greater than the momentum of the piston and connecting rod at any ordinary speeds, and is the real cause of wearing rather than is the weight of the reciprocating parts.

Importance of Proper Lubrication.—Much of the wear of the cylinder walls, piston rings and bearings is caused, not by the work or movement of the parts, but either by improper lubrication or by the presence of grit on the working surfaces. Improper lubrication need not be considered here, although it is quite evident that oil which does not remain on the cylinder surfaces but allows them to get dry when hot is not conducive to smooth running nor long life.

Grit and "Carbon" in the Engine.—Grit is the destructive agent in automobile engines and is derived usually by way of the carburetor from the road surface, being drawn in with the air breathed by the engine and caught by the oily walls, which it then helps to destroy. Much of the so-called "carbon" found in an engine cylinder is merely road material, and from this source. Users who wish to keep their engines smooth-running and powerful should see that the carburetor intake is provided with proper air filters to exclude the dust and grit and deliver pure air to the engine. Were this a common practice, there is no doubt but that a much higher piston speed would be practicable under present constructive conditions, which would permit either longer strokes or higher rotative speeds, as the designers might prefer.

Importance of Proper Lubricating Oils.—While lubrication is fully treated under its proper heading, we may say in this connection that piston speeds are affected by the quality and variety of oils as well as by the quantity. For high speeds, as has been proved, a loose piston copiously oiled will move with less friction than one properly-fitted and oiled in the usual manner; also, a thin oil will offer less resistance to high speed than a thick oil. In fact, while thick

ils are usually recommended, because of their packing abilies, they are liable to become so stiff in engines that are ept at a low temperature by excessive cooling as actually to sist the piston movement, rather than assist it by superior acking; thus lessening, instead of adding to the powerutput. The user must learn to determine for himself which rade of oil his engine needs, and should buy oil according his best judgment, rather than according to the price. ils looking much alike vary widely in quality, and should e accepted by test, instead of by appearance. Thus, a good uality having been found, should be used, because a good l, suited to the engine, will save fuel and promote economy remaining on the cylinder walls and preventing them from earing. Also, it does not need replacing so often as an ferior oil, which, by smoking away and otherwise disappearg, leaves the walls dry and permits them to be scored and estroyed, as well as permitting the escape of the gases, and eeding to be fed in larger amounts to secure anything like tisfactory results.

Speed and Fuel Economy.—In connection with piston peeds, it is desirable to emphasize the fact that the exploded ases should be expanded as rapidly as possible, if economy desired. The product of combustion is heat, which exands the gases, thus producing pressure. If this pressure utilized the heat expends itself in that way, but if this ressure is not utilized, the heat is lost through the walls the engine and the pressure falls in the cylinder even ough no expansion is permitted. If the cylinder walls are hot as to carry off very little of the heat of the newlypanded gases, then the engine may be run at slower speeds ith good economy, but, in general, the theory that the iston speeds should be as high as possible for the sake of onomy is correct. This fact, however, must always be onsidered in connection with the needs of the user. There manifestly no economy in running an engine at high speed, urning many charges of fuel to do work which a smaller umber of engine turns and fuel charges would accomplish, nd, on this account, it is usually more economical to drive n the high gear, burning full charges only infrequently, ther than to use part charges with the engine turning rapily and propelling the vehicle by the use of the low gear. his point is made clear because many users, having a small eoretical knowledge, fail to grasp the significance of this, nd believe that they are saving their engines and vehicles y driving on the low gear, with a high engine speed.

Long-Stroke Engines.—The novice in the automobile usiness hears much talk about the stroke of the motor, hich has largely arisen from the fact that some years back e French racing authorities decided to attempt to limit e size of racing machines by limiting the bore of the gine cylinders, and this at once compelled designers striv-

ing to produce a larger engine than their competitors to increase the stroke, with the result that automobile engines are occasionally found with strokes two to three times as long as the diameter of the cylinder. Such engines are very properly termed long-stroke engines, but since no authority has determined the relation between bore and stroke necessary to entitle an engine to pass as long-stroke or short-stroke, these terms are very vague and much abused, being often employed in advertisements and elsewhere to designate engines to which there is no sound reason for their use.

Advantages of a Short Stroke.—The earlier engines, both steam and gas, were necessarily produced on more or less imperfect lathes and it was easier to bore a long hole in a cylinder of small diameter than a larger one of shorter length. This fact militated against large bores. Further, the small piston weighs less and costs less than does the large one and therefore was easier to produce. But, as automobile designers learned their business better, they concluded that the shorter and more compact an engine can be, the better adapted it is for automobile work; that increasing the bore increases the capacity of the engine, and, consequently, its power, directly as the square of its diameter, whereas increasing the stroke simply decreases the mean effective pressure on any given compression pressure. The short-stroke engine requires a shorter and stiffer crank-shaft, a smaller crank-case, a shorter cylinder and connecting rod, and thus in more ways than one adds to the light weight and large power required to propel the vehicle. It was the adoption of these features, together with a high rotative speed, which permitted the solution of the problem of automobile design. Whereas the first engines employed resembled stationary steam and gas engines in that they were of long strokes and small bores, later designs were made with larger and larger bores and shorter strokes, until after a decade of experience a number of engines were produced having bores larger than the stroke, in some cases very much larger, as 6-inch bore with 4½ stroke or in one instance a four-cylinder engine having 5⅛-inch bore by 2½ stroke, the cylinders being opposed and the pistons connected in pairs and operated by a modified crosshead or Scotch yoke. Just where this progress would have ended is not apparent but it is certain that designers were not following any artificial lead or false trail but were making progress toward lighter, more compact and more powerful engines.

Meaning of the Term Long Stroke.—The term "long-stroke" should be used to express a definite relation to the bore, thus an engine of 3-inch bore and 6-inch stroke or more is very properly a long-stroke engine, although the length of the stroke, viz., 6 inches, is not long. In another sense and usage, all engines having strokes of 6 or 8 inches, or less, are

roperly short-stroke engines, as distinguished from those f larger size, with strokes necessarily much longer. This econd use of the term, however, is not largely found in utomobile practice, nor is it properly applicable there. Just rhat proportion would be proper, to distinguish the long-troke engine from the short-stroke, is not for this article to iscuss, but from common practice it would seem that, unless ae stroke is more than one and one-half times the bore, the ngine is not one of long-stroke. The growing demand for till lighter engines to meet the needs of the makers of the apidly increasing number of light vehicles will undoubtedly ompel designers to again consider the short, compact and owerful designs secured by the use of short strokes; and etter workmanship each year will insure the same perfection ı production of the larger bore that is found in the smaller-ore cylinder.

Limitations of Long-Stroke Engines.—While some phe-omenal results have been shown by long-stroke motors, ıey have mostly been secured by forced lubrication, by ex-eptional workmanship, by employing piston speeds far be-ond the accepted practical speeds and by similar means 'hich are permissible on the race track or in contests but are ot considered practical by the average motor-vehicle user. t is interesting to note that in aviation practice, where high ower and light weight are absolutely essential, the long-troke motor has not found a place and it may be safely ac-epted by the user as not being the best form but being a ıd or fashion fostered by law-makers who, in their ignorance r for the purpose of securing convenient calculations, con-dered the bore in calculating horse-power. That the law-ıakers and tax collectors will long continue to permit such vasion is not to be expected and when both bores and rokes are again free from such considerations the progress ı motor building will take up its untrammelled way, which ıe laws and regulations referred to interfered with.

CHAPTER XVIII.

Cylinder Compression.

Elements in Compression.—The term compression, as applied to the gas engine, is very often misused. Many an engine operator, turning over his motor by hand to ascertain its condition, announces that he has a high compression, when he really means a good compression, or bewails the low compression, when a leaky valve is responsible for a poor one. The distinction, which should be clearly borne in mind, is that a good compression is the kind the engine maker designed for, and, doubtless, secured when the engine was built; whereas a poor compression is one which fails to achieve that standard. A high compression, on the other hand, is one which, if good, is measured by a high number of pounds gauge pressure or by considerable resistance to turning over the engine by the starting crank. A low compression does not offer this resistance nor does it show this comparatively high gauge pressure, but a low compression may be a good compression and many people believe that for automobile practice a low compression is better than a high one.

Determining the Compression.—Whether a compression is good or poor is determined by the length of time required for the compression to escape from the cylinder. If, when turning the engine by the starting crank, the compression will resist the operator for from about ten seconds to a minute or more, unless violently forced over, it may be considered good; but if the engine must be turned rapidly, in order to perceptibly feel the compression, and, if the compression escapes so rapidly that, in turning it over, one meets no resistance unless turning fast, this compression is said to be poor, or the engine is said to be leaky. A good compression should throw the engine backward ten to twenty-five times when the piston is turned against it and the starting crank released. A poor compression will not do this, but will allow

the gas to escape during two or three attempts to pull against it and release the piston.

High and Low Compressions.—Compressions are, of course, relative matters. A high compression for one engine, or for one purpose, may be extremely low for another. In automobile practice, compressions of between 40 and 60 pounds are considered low; compressions of between 60 and 80 probably are considered medium; while high compressions would run up to or above 100 pounds. Some years ago it was considered good practice to carry the compression of an automobile engine high, but engine makers and users have learned that for the purposes of an automobile engine a high compression was not so good as a low one. Roughly speaking, the high compression engine is considered a speed engine, while the low compression engine is better adapted for slow, heavy, power-requiring work, or, to put it more tersely, the high compression engine is a racer, whereas the low one is for draft service.

Uses of Compression.—Before going more deeply into this matter of compression, it is well to consider why a gas engine requires such an arrangement and what its function is. The gas engine, like the steam or compressed-air engine, derives its power from the push of the expanding air or gases in the engine cylinder and of course, generally speaking, the higher the pressure of the working charge of gas, the greater the power to be derived from that particular stroke of the piston. On this account it would seem that high compression is more desirable than low compression and many automobile engine makers have erred in this assumption. Unlike the steam or compressed air engine, the gas engine takes its charge into the cylinder at atmospheric pressure or approximately such. This charge is then compressed into the firing chamber or clearance space, also often called the compression space, and while this gas is compressed into this small space it is ignited. The ignition liberates the heat of the fuel and expands the gases, but since the gases are confined and cannot expand in volume beyond the cubic content of the cylinder, the result of this expansion is a greatly increased pressure.

Average Compression Figures.—The usual gas engine charge expands sufficiently to raise the pressure from two to five times the compression pressure, probably three times as an average, which, for purposes of comparison may be the figure used. If the compression is raised to 100 pounds and the ignition expands this to three times this pressure, it will be seen that there is a total working pressure of 300 pounds to the square inch, whereas if this charge had been compressed to but 50 pounds originally and then expanded to three times the original pressure, the gain in pressure would have been but 100 pounds, or half as much as in the original instance.

At first thought, this difference in pressures seems to be wholly a loss, but such is not the case.

Compression Versus Volume.—Increasing the compression does increase the power of the engine, increases the efficiency, and adds to the economy, but, where one engine gains in high working pressures another engine gains by a larger working volume. Thus, if the pressure originally rises to 300 pounds, because of a small combustion chamber (half the cubic content of the one employing the lower pressure), it is evident that this pressure must fall quickly, because the small combustion chamber does not contain as large a volume of gas to expand and follow the piston movement. In the low compression example, the compression chamber being double the size has double the volume of gas at 150 pounds compression, which the former example had at 300 pounds, and because of this larger volume the piston is followed more fully. In other words, the indicator card taken from a high compression engine shows very high pressures with rapid falling and reduction of pressure, but the low compression engine showing low pressures at the beginning holds those pressures better, and commonly exhausts at higher pressure. This exhausting at higher pressure is not a gain in economy, nor in efficiency—it is, in fact, a loss—but the steadiness with which the power is applied during the firing stroke renders it possible to make the engine lighter, and enables it to pull more steadily than the high compression engine, in which the sudden pressures come rather as blows than as pushes.

Considerations Involved in Compression.—Having seen the matter in this light of low compression, the question arises as to what is the best compression, and, even, as to whether it is advisable to compress the charge at all. The answer most certainly is in favor of using compression, for the reason that a non-compression engine must be quite large for a given power, and, being large, it has more piston friction, more probable leakage around the piston, more heat loss because of the large amount of cylinder-wall surface, as compared with the total mass of fuel burned, and, because, working at low pressures, it cannot work so fast, and, therefore, must be larger, in order to develop a given power. On these accounts the fresh fuel charges in a gas engine are, and very properly should be, compressed, but to what point is a matter best answered by experiment rather than by theory. Certain it is that the "negative work" done by the piston in compressing the new charge is small, as compared to the piston work gained by the engine from the greatly increased rise in pressure, following the combustion of the charge.

Uses of High Compressions.—In stationary engines of *the Diesel,* and similar types, the compression is carried to *an extremely high* figure, oftentimes as high as 500 pounds

per square inch. Of course, such high compression would involve certain pre-ignition, if the fuel was contained in the compressed charge, but in these engines only pure air is compressed, and the fuel is injected at the ignition point. So hot is the compressed air at this point, that no ignition device is needed, but the heat of the air immediately ignites the fuel, as it enters, and the new charge burns as fast as the fuel is admitted, instead of burning more or less explosively as in the common type of engine. The fuel economy of the Diesel engine is quite high, its efficiency being well up to 35 per cent. of the total heat units of the fuel, whereas the average automobile engine probably does not transform more than from 15 per cent. to 20 per cent. of the total heat into power.

Troubles with Excessive Compression.—Since considerable "negative work" is involved in the act of compressing the air to such high pressures, and since the engine must be very heavily and strongly built, to withstand such high pressures, it is not probable that such types of engine will find use in automobile work. Any engine using the injection method of feeding fuel requires more time to complete the combustion than does an engine employing a mixed charge, which, being mixed before it enters the engine, and still more completely mixed during the compression stroke, is ready for quick and complete combustion when ignited.

Compressions and Fuel Mixtures.—While it is possible to vary the quality of the mixture within a considerable range, and to secure high economy and great efficiency from very lean mixtures at high compressions, or with hot engines, it is usual to design the engine so as to run satisfactorily with mixtures of maximum "fatness." This is true because the average user will too often increase the "fatness" of the mixture, in the hope of getting more power, whether he really achieves this result, or not. This is the one great objection to the gas engine, viz., that the user, knowing the fuel to be the source of power, imagines that the power must be increased, if the fuel proportion is increased. Many experiments have shown, however, that this is not true beyond a certain maximum point, and that it is scarcely true beyond a medium fuel-proportion point. In other words, experiments show that a certain proportion of fuel must be added to the air to get combustion at all, this proportion of course depending upon the heat of the cylinders, in which the charge is compressed, and the amount of the compression. From this minimum, the power will increase in a fairly constant ratio, until sufficient fuel is provided to properly burn the air contained in the new charge.

Perfect Mixtures and Perfect Combustion.—Because of the difficulty of securing a perfect mixture, that is to say, one in which each atom of hydrogen or carbon is united with *its one or two atoms* of oxygen, as the case may be, the

perfect combustion is seldom secured. The nearest approach probably follows the use of a rather lean mixture, in which there is an insufficient amount of fuel for perfectly consuming the available oxygen, and, therefore, not as much heat and power is developed, as would be the case were more fuel supplied.

Power and "Fat" Mixtures.—Experiments show, however, that adding more fuel does not add power, proportionately, but that, after a certain proportion of fuel is supplied to any given quantity of air, further additions add some power, but not in proportion to the fuel added, and that this condition continues true until the mixture is composed of nearly twice the amount of fuel used for the best conditions of power and economy. After this high and wasteful fuel proportion has been reached further additions of fuel result in failure to burn the air to carbon dioxid gas. The result is that heat fails to be properly generated, and the power of the engine falls with considerable rapidity. This latter effect is due to the peculiar fact that, in burning, each particle of carbon in the fuel will unite with one particle of air, forming carbon monoxid gas and liberating one unit of heat in this union. Should this same atom of carbon unite with another atom of oxygen it would form carbon dioxid gas, and liberate, approximately, six times as much heat as in the former instance, and this is the great reason why plenty of air must be furnished and proper combustion secured.

Compression and Fuel Combustion.—With this explanation we are now able to understand (1) why, beginning with compressed air and adding fuel, as in the Diesel engine, there is no result, until sufficient fuel is added to permit combustion; then (2) why the power increases to the point where all the fuel is burned to carbon dioxid, and very little free oxygen remains unconsumed; next (3) why further addition of fuel burns more or less of the unconsumed oxygen, with slightly increased heat, but with more or less passage of unburned fuel from the engine; and finally (4) why, with a sufficient excess of fuel, the oxygen combines and forms carbon monoxid, instead of combining properly, and forming carbon dioxid. At both extremes of this combustion range, failure to ignite under ordinary conditions is found; the lower failure being due to insufficient fuel, and the upper due to insufficient air.

Blending the Fuel Mixture.—As is well known, an electric spark may be formed in the bottom of a can of gasolene, or in the bottom of a can of coal gas, or of fuel vapor, without igniting the contents, simply because there can be no combustion, without the presence of oxygen to unite with the carbon of the fuel. This is largely the situation existing in the cylinder of an engine when the mixture is overfat. In the case of a lean mixture, it is often possible to secure com-

ıstion, if the engine is hot, because a mixture too lean to ırn will, if heated, develop a total amount of heat sufficient › support combustion. The same result follows on com-:ession of the charge: consequently, a high-compression en-ine may use extremely lean mixtures, and this is in the line : high economy.

Economy and Efficiency.—The reader must not mistake :onomy for efficiency. Economy is the production of a iven good amount of power with the use of a small amount f fuel; whereas efficiency may mean a large power realized 'om a small engine, a sense in which the term is often used y the average user. As a matter of fact, efficiency and conomy usually go together. That is to say, the efficient ıgine delivers a large amount of power from a given quan-ty of fuel, just as does an economical engine. But to use a .rge engine with an extremely economical mixture may not e an efficient procedure, because of the friction of the parts, ıe amount of lubricating oil required, and similar losses, ot strictly considered, when considering only the use of an :onomical fuel mixture.

Requirements in Automobile Engines.—In automobile 'ork these matters must be considered from the point of :tual practice, under the varying conditions of daily service, ıther than from the point of the user of the stationary en-ine. The automobile engine must embody the following ualities: (1) it must be light in proportion to its power; (2) ıust be able to run at a considerable range of speeds; (3) ıust be readily throttled, so that it may be stopped and tarted quickly; (4) must be easily started. These, and other imilar virtues, are not necessary in a stationary engine, 'hich, once started, probably runs all day under constant peed, and with fairly constant load; has fly-wheels suffi-iently heavy, and a cooling system, sufficiently constant in peration, to insure steady conditions. The stationary engine ıns well with hot tube ignition, because this can be adjusted ɔ give proper results at the desired speed, and, since the ngine maintains this speed, there is no need for readjust-ıent; further, the hot tube will fire with certainty, lean ıixtures, which the electric spark, commonly used in auto-ıobile practice, would fail to fire.

Best Automobile Compressions.—Because of the require-ıents of automobile service, and of the light fly-wheels em-loyed, and the light construction of the engine, together 'ith the fact that the engines run hot, since cold cooling-'ater is not available, compression pressures must be kept :latively low. Thus, it is becoming more generally accepted ıch year that pressures of from 40 to 60 pounds, or slightly igher, are better for everyday work on American roads than igher pressures. Such low compression engines are more exible, and, when throttled down, hold to their work more

tenaciously than those having higher compressions. Further, pre-ignition is less likely, and the cooling problem is less severe.

High Compression and Self-Ignition.—It will readily be seen that, with a high-compression engine, the heat arising from the work done on the gas, in compressing it, may carry the temperature up to the igniting point, particularly if the walls of the engine are hot, and add their heat to the compression heat. Self-ignition is not objectionable, provided that it does not occur prior to the proper point in the cycle. The charge of gas, heated by the cylinder walls and by its own compression to practically the igniting point, requires but the slightest of electric sparks to complete the ignition and render it operative. Further, such a charge, if properly mixed, is in the most perfect condition for burning, because the particles of fuel and oxygen are in proximity to each other, and are ready to unite. Pre-ignition, however, which is objectionable, differs from self-ignition only in the fact that it occurs too early in the stroke, and causes negative work. Thus, if, instead of igniting at the upper dead-center, and allowing the expansion of the gas to help the piston forward on its downward stroke, the ignition comes ahead of dead-center, the pressure resulting therefrom will retard the upcoming piston; in some cases reversing its direction, in others, simply stopping the engine, with a more or less abrupt jerk, unless the fly-wheel is very heavy. In any such case the engine loses power, pounds and shows other symptoms of being overhot.

Advantages in Low Compressions.—In the low-compression engine there is a much larger compression space, consequently lower compressions, and the temperatures of compression do not rise so high. If in such an engine ignition occurs slightly ahead of dead-center, the combustion is not so rapid, and the pounding not so likely to be heard, or, if heard, not so severe, because of the large space into which the burned gases are compressed. The experience of many users may be safely accepted in these matters. Thus it is that the low-compression engine is winning favor for daily use, because of its smoothness, involving only slight strains on the bearings and engine parts; its freedom from pre-ignition; its ability to use fat mixtures, when desired, and the easy starting, which the low compression permits.

Variable Compression Engines.—There have been many suggestions of variable-compression engines; that is to say, engines which could have a high-compression space, when high speed is wanted, or a low-compression space, when moderate speeds, with much power, are required. To secure this variable compression adds some mechanical complication, and few successful engines have been employed therewith. Instead of varying the size of the compression space,

a number of engine designers have sought to vary the size of the new charge by a variety of methods. Thus, in the Adams-Farwell engine the throttle controls the inlet valves; if a full charge is not wanted the inlet valve is held open, allowing the charge to be pushed back into a distensible leather bag, which holds it until drawn out by the succeeding suction stroke or strokes. In this way, only such quantity of new

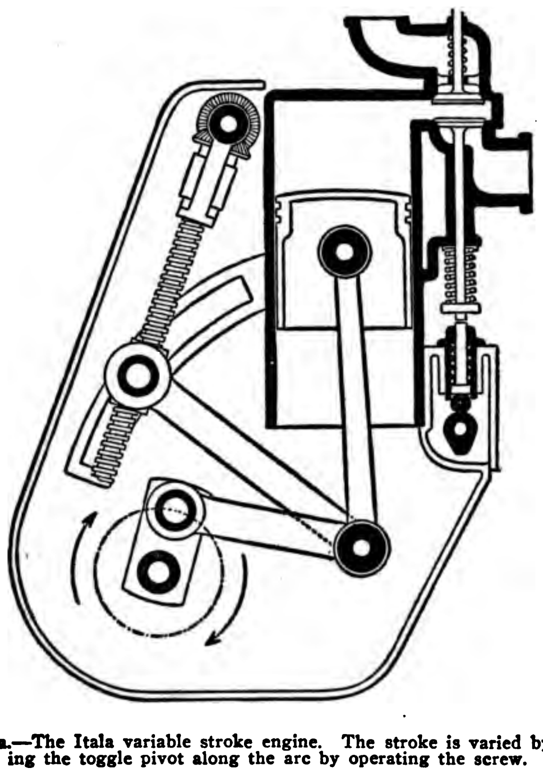


Fig. 18a.—The Itala variable stroke engine. The stroke is varied by moving the toggle pivot along the arc by operating the screw.

charge as may be desired is retained in the cylinder for compression. This results in very low compressions, when little power is wanted, and practically no compressions at all during the time of starting; so that this type of engine, when used in aeroplane work, is readily started by the propellor if the plane has appreciable motion through the air. The slight complication of this arrangement, however, has not been in its favor, and most designers have avoided it.

Variable-Stroke Engines.—Among engines of this class the Itala engine is the most notable. It shows an attempt to effect fuel economy by reducing the capacity of the cylinder. By a crank, within reach of the operator, the screw shown is turned and the long link is shifted in its position. When its pivot is near the top of the arc the stroke of the piston is very short: when near the bottom the stroke is long. The position of the arc is such that the piston stops, when at the top of its stroke, in the position to yield proper compression. The indicated arcs show the approximate motion of the connecting pin which joins the links. This engine has been built with a bore of 130 mm. and strokes variable from 90 to 300 mm. A ratio of 3⅓ to 1. This is as much reduction as the usual low speed gear, so it would seem capable of taking the place of the usual two-speed change gear.

CHAPTER XIX.

Cooling the Cylinder.

Cooling and Heat Economy.—Both steam and gas engines are heat motors, and depend on the heat in the steam or gas for their power. In the steam engine the steam is usually not of high temperature, and great precautions are taken to avoid loss of any of it. The cylinder and pipes, as well as the boiler, are jacketed with heat-insulative material to save heat, and secure the desired power, with the smallest consumption of fuel. In the gas engine, on the other hand, the temperature of the combustion is so high that the cylinder and piston would be damaged, if they were allowed to approach it. This is why the gas is burned in small charges, so that only a small amount of heat is generated at a time, in the cylinder, instead of in a reservoir, where the excess would be destructive. It is, further, necessary to cool the walls of the cylinder to prevent damage, also to prevent pre-ignition of the charge by the heat of the walls, and, when poor oil is used, to prevent boiling this oil away and leaving the cylinder walls dry, almost sure to damage, and unable to deliver power, because of the great friction of the dry piston on the dry wall. Beyond precautions to prevent these undesirable conditions, the hotter the cylinder the better, because leaner mixtures may be used, and the heat remains in the gas, to be turned into work by expansion, instead of being absorbed by a cold wall, and turned to waste.

Conditions of Combustion in the Cylinder.—The internal combustion engine is dependent for its operation upon the heat produced by the combustion within its cylinder, of a hydrocarbon gas, the vapor of gasoline, or other fuel, mixed with the proper proportion of air, and fired at the proper time by electric spark, hot tube, hot plug, high compression or some other convenient means. The products of combustion contain, of course, the inert nitrogen of the air, water vapor, formed by the union of oxygen from the air with

the hydrogen of the fuel, and several carbon compounds,—either carbon monoxid, in case of insufficient air, or carbon dioxid, if the combustion is practically perfect. It is quite evident that the water vapor, when condensed as water, occupies much less space than the original gases forming it, while, as is generally known, carbon dioxid is considerably heavier than the atmosphere, so much so, in fact, that it may be poured from one jar to another much as can liquids. Since these products of combustion are heavier than their original constituents, it follows that they have acquired this density by making new forms which require less space, and the pressure generated in the engine cylinder is not due to the increase in volume of the gases per se, as is the case when gunpowder or other real explosive is detonated, but this explosion is due simply and solely to the heat generated by the combustion.

The Need of Conserving the Heat in Cylinder.—While in these pages the combustion of the fuel in cylinder is frequently spoken of as an "explosion," it is to be understood by the reader that no explosion in the true sense of the word takes place, but simply a rapid combustion, so rapid that the effect very closely approximates that of an explosion, and for convenience that term is used. Since this gaseous expansion, as also the power resulting from it, is dependent upon the heat generated in combustion, and since these gases quickly lose their heat and reach their limit of expansion, it follows that, to preserve this power as fully as possible, the heat generated should be preserved. In short, gas engines are heat engines, operating through the expansive energy of heat, just as truly as is a steam engine. The steam engine cylinder is jacketed with non-conducting material, to avoid condensation of the steam, with consequent loss of heat and energy; so, also, gas engine cylinders should be kept at as high a temperature as will permit proper working conditions.

Working Temperature of the Engine.—In a heat engine, as elsewhere explained, the temperatures should be as high as possible, in order that the heat of the expanding gases may expend itself in doing work, and not be absorbed, carried away, and lost in the cold walls of the cylinder, or water jacket, or by any excessive cooling methods employed. Just what is the best working temperature is a matter that cannot be stated offhand, since it depends upon (*a*) the design of the engine, (*b*) the speed at which it is to operate, (*c*) the compression pressure, (*d*) the quality of the mixture, and, also to some extent, on the nature of the fuel. But, as a general rule, the engine should be kept as hot as may be possible, without causing pre-ignition, or, in other words, *nearly* hot enough to cause the explosive charge to ignite *itself.*

The Need of Regulating the Heat in Cylinder.—Unfortunately, however, the temperature of the flame of the burning fuel within the cylinder is much higher than either the lubricating oil or the metal of the cylinder can withstand; consequently, it becomes necessary to provide against overheating, which would soon end the usefulness of the engine. Trouble may arise from burning of the lubricating oil and from the high temperature and warping of the metal. Also, if the fuel is mixed with the air prior to introduction into the engine, as is common in automobile practice, then the heat of the preceding charges, remaining on the walls of the cylinder, may be sufficient to ignite the new charge before the proper ignition point. This would cause expansion before the piston has passed its dead-center, which would either result in "negative work," or back pressure, with consequent loss of power, even if not sufficiently powerful to stop the engine, as sometimes happens.

Self-Ignition Temperatures.—The difference between "*self-ignition*" and "*pre-ignition*" must always be kept in mind, in this connection. There is no objection to self-ignition, as a regular method of firing the fuel charge in a gas engine, so long as this ignition does not take place too far ahead of the proper time. In such an event it is called pre-ignition and is objectionable. The temperature of self-ignition can hardly be stated with any degree of accuracy because a fat mixture,—that is, one containing a large proportion of fuel—ignites, more readily than a lean one; also some fuels ignite more readily than others. But probably, under usual conditions of operation, the walls of the cylinder may be permitted to reach temperatures of from 500 to 600 degrees with perfect satisfaction, and without involving the danger of self-ignition, if proper lubrication is provided and the compression is not too high.

Heat and Efficiency.—Those who have attempted to start a cold engine have noticed the fact that the steam condenses in the cylinder of the steam engine, and will not propel, till the cylinders are warm; likewise, that the first explosion, such as would start off a warm gas engine at speed, may barely turn over the cold one. The cold walls absorb all the heat, and there is none left to turn into power; and it takes some little time to absorb this heat. By the use of high fire-test oils, the temperature of the walls of the cylinder may be as high as 350° to 500° Fahr. Pre-ignition of the mixture may be prevented by using a smaller proportion of fuel, with greater economy, although with slightly lessened power. Most modern automobile engines have ample power, and so need not be run with mixtures of maximum strength, as might be the case, if under-powered.

***The Practical* Limits of Cooling.**—Because of these *considerations,* the common practice is to cool the engine

cylinders by water or air on the outside. The water cooling method is the most common one, since it requires the least ingenuity on the part of the designer, and since there is less doubt as to its performing its function. Many automobile users seem to think that the cooler the engine the better, and they give preference to large water jackets, large radiator systems, and exceedingly active fans which keep the temperature of the water well below the boiling point. Experience has shown, however, the fallacy of this practice, and at the present time, water-cooled engines are kept as warm as possible, even allowing the water to boil in the jackets, on the theory that it is best to save as much of the heat as can be retained in the working charges, and to take away from the cylinder walls only that excess necessary to prevent pre-ignition or faulty lubrication. Oil refiners, however, have provided oils of such high fire test, up to 800 to 850 degrees F., that the lubrication of the walls needs very little attention, and pre-ignition is the principal limiting factor to be most considered in engine cooling.

Engine Cooling and Efficiency.—There are many other features to be considered in connection with engine cooling. When we remember that only a small portion of the energy contained in the fuel is transformed into work by the average engine, we should not ignore any means that will increase this portion to a more satisfactory amount. Roughly speaking, probably 15 per cent of the fuel energy is expended as work while 35 per cent passes away in the exhaust gases and another 35 per cent into the cooling system. Other losses, such as direct radiation, imperfect combustion, etc., make up the remainder. We cannot lessen the amount of loss to the exhaust, without some better method of expanding the working charge than is at present used, but we can save some portion of the heat that usually passes into the cooling system, and if we make use of high wall temperatures, we save part of this loss and, correspondingly, increase the power and the loss into the exhaust.

High Temperatures and Exhaust Losses.—On first thought, it would seem that any heat energy saved from the walls would expend itself wholly in producing greater power, but this is not the case. It simply increases the area of the indicator card to the exhaust point, and, of course, exhausts more heat when the valves are opened. A study of an indicator card, with the working line placed slightly higher, shows this increase in power, also, that more energy passes into the exhaust.

Spark-Timing and Fuel Mixtures.—The cooling is also much affected by the time of the ignition, the quality of the mixture, the fit and surface of the piston rings and the *speed of the engine*. The timing of the spark should be such *that the gases* generate their heat when the cylinder sur-

face is smallest; that is to say, the combustion should take place at the very beginning of the out-stroke, at which time the energy is transformed into pressure, and begins doing its work on the piston. If the ignition of the new charge is delayed until later in the stroke, the amount of cylinder wall surface exposed to the flame is very much larger. In this case the opportunity to utilize this power by movement of the piston is less, so there are two losses, which, for a given power, manifest themselves as excess heat, because the lessened power of each charge requires the use of larger charges. This is the one great reason why a properly advanced spark is both economical and keeps the engine cooler.

Quality of the Flame of Ignition.—There seems to be more radiant heat in a yellow flame than in a blue one, that is to say, more heat which expresses itself by radiating into and through the cylinder walls. Consequently, a slow-burning, fat mixture, showing a yellow flame is more heating to the cylinder walls than the quicker-burning blue-flame mixture. If the piston rings properly fit the cylinder walls, and hold the gases from escaping, less fuel is required to propel the car than if they are leaky; and if gases can escape past the piston rings, they carry into the wall and rings much heat, which should be expended in doing work, and also require the use of larger charges for a given duty, with a consequent increase of heat.

The Effect of Rapid Expansion.—The Carnot theory of the gas engine calls for rapid expansion of the gases, which means that, if they can be expanded quickly, their energy is used to propel the piston, rather than to heat the cylinder walls, and, consequently, rapid expansion keeps the walls cooler. It is advisable, therefore, other things being equal, to use smaller charges and high piston speeds. There are many other considerations to be dealt with in actual practice, so that this latter statement may not be of much practical value, but it is made to assist in a better understanding of the cooling problem. That the engines of the future will run with practically no cooling whatever seems to be an assured condition, but, for the present, water-cooling is the prevailing method, with the air-cooling making good progress toward popular favor.

Relation of Compression and Temperature.—This matter of compression should be considered in connection with the temperature matter. Thus, while a charge of cold fuel mixture, compressed in a cold engine, may require compressing up to 400 or 500 pounds, in order to generate sufficient heat to ignite properly, as is done in the Diesel engine, yet as recognized in automobile practice, compression pressures of 100 pounds or thereabouts give rise to very objectionable pre-ignitions with "pounding" and loss of power. It is very generally admitted that, for daily service, a moderate

compression, as from 55 to 65, or even 70 pounds by the gauge, is preferable, and that with such pressures, a temperature at ignition of 500 degrees in the cylinder walls is undoubtedly practical.

Wall-Thickness and Temperature.—The thickness of the cylinder walls is a matter also to be considered. The thin wall carries the heat away from the interior surface much more quickly than does a thick wall, and, consequently, can permit a higher temperature during operation. Stated otherwise, heat travels slowly through the cast iron wall, and the interior surface may be quite hot, while the temperature of the exterior is not objectionably high. But, if the wall is thin, there will be no such a wide variation in temperature; consequently, the outer surface affords a much more exact criterion of the condition of the inner surface. This point is of particular advantage in air-cooled engines, which cannot, and do not, attempt to keep their cylinder outsides so cool as is the common practice in water-cooled engines.

Water-Cooling and Air-Cooling.—In the water-cooled engine the outer surface of the wall is kept down to about the temperature of the water. This cannot be much above the temperature of boiling water (212°) or the water would boil away, and it is too frequently far below this. In the earlier days, many thought an engine that was too hot to allow the hand to rest on the water jacket (about 120°) was not properly cooled, but experience has shown the fallacy of this, and most designers now aim to secure temperatures as near as possible to that of boiling water (180° to 200° F.) But even this is so far below the permissible temperatures that it does not show the greatest economy, as is proven by the large number of efficiency contests which have been won by air-cooled engines. The difference in economy between walls at 200° and walls at 400° is well worthy of consideration. There is also a difference in the ease of cooling. The engine that must keep its walls at 200° must get rid of this increased quantity of wasted heat, and is not so well able to do it. It is clear that water at 190° will not lose heat to the atmosphere, which may often be at 90°, so fast as will the metal surfaces of the cylinder having its walls at 390° or higher. Heat radiation proceeds about as the 4th power of the absolute temperature. (Thermometric temperature plus 466° F.) This explains why air-cooled engines succeed in hot climates, where water-cooled engines fail. If the temperature of the air is very high, the water boils away so easily, that refilling the water system becomes a nuisance, and the major portion of the heat must be absorbed by the steam, becoming "latent heat," rather than be carried away by the air. With the air-cooled motor, having walls at 400° or thereabouts, there is still a wide margin for cooling between *the wall temperature* and the air, even though the air is *above 100°.*

Air-Cooling Devices.—These remarks explain the great differences in the two systems of cooling. Air-cooling is the older system, but, not being well perfected in the early days, it gave way to water-cooling, which has attained the greatest popularity, and has been carried to a high degree of perfection. The first and simplest forms of air-cooled cylinder had circumferential ridges, or flanges, cast on the cylinder walls and head. Others had the radiating surface cast in longitudinal ribs. In both cases, the deeper the rib or flange, the less likely is the air to get to its base, where the heat is greatest. The flanges can hardly be cast in the same weight and thickness on all sides, on which account the cylinder, in expanding under heat, cannot expand evenly. The other portion of the flange expands less than the cylinder wall, with the result that the wall becomes wavy, as may often be noticed by looking at the inner surface of such a cylinder that has seen some service. These irregularities, coupled with the use of unfit oil, make it almost impossible to get first-class results from such an engine. To admit the air more freely, cast spines have been employed, instead of flanges, or ribs, but these do not expose a large surface, and break off easily. They are very efficient, however, and do not distort the walls. To secure still better results.

CHAPTER XX.

WATER-COOLING.

The Cylinder Water Jacket.—For water-cooling, the cylinder must have an outer shell, or casing, forming the water jacket. This is usually cast in place, forming part of the cylinder. It adds quite a little weight, if so made, and, at the junction with the wall, forms warping or distortion points. These are not of much importance, however, because the wall does not get very hot, when water is present. In some instances, the jacket is of sheet copper, and is applied to the cylinder in the machine shop. This permits machining the cylinder on the outside, and proper inspection of the material, not possible under a water jacket cast in place. It also saves some weight, and, being thin, does not distort the wall by warping. From the jacket the water is led to a radiator. This is usually placed at the front of the car, where the air can strike it, and offers a large surface for the transfer of heat to the air, which cannot take place very rapidly, because of the low temperature of the water, as compared with the usual temperature of the air. From the bottom of the radiator, the water is piped back to the bottom of the cylinder jacket, to be again heated by the wall, and thus to carry the excess heat away. It is well known that hot water will rise and cool water fall, if free to do so, in a water system, and many cars use this material (thermo-syphon) system of circulation. Its simplicity commends it, and it is growing in favor. It requires large piping and a slightly larger radiator, but saves the power required to drive a pump. Most makers favor the pump circulation, and introduce a centrifugal or gear pump in the bottom or return pipe. One objection to the pump system is that it circulates the water, whether cold or hot, and so tends to keep the wall too cool. The natural circulation acts by the wall heat, and thus circulates very slowly, when the wall is too cool, and very fast, when it becomes hot. It adds to economy by this natural thermostatic action. Behind the radiator most makers fit a fan, to

insure a faster movement of the air than that produced by the vehicle. This is practically a necessity, when the engine is running fast on the low gear, as in hard pulling, for then the vehicle moves very slowly. The water systems, not only are more complex and costly, but they take power, and add weight. They are, also, objects of solicitude in freezing weather, and require to be kept warm, or filled with some non-freezing solution. Also, they interfere with accessibility, and, being delicate, leak frequently. But they have one strong point, viz., since water cannot be overheated, because it will boil away, and hold its temperature at 212°, it is not easy for an ignorant or careless driver to abuse his motor.

Regulating the Cooling Action.—Some designers using water-cooled engines have closed the system, with the result, that, when the water boils, some pressure is generated,

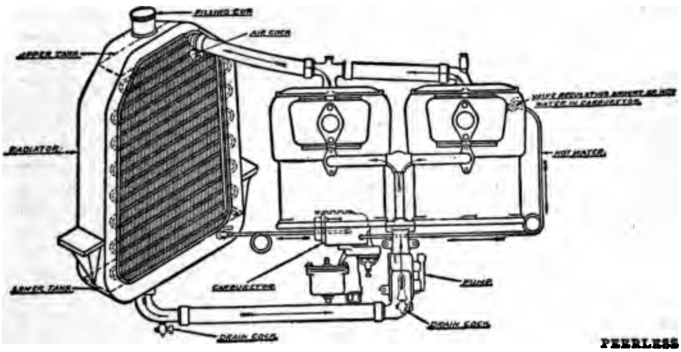


Fig. 20a.—Diagram of a typical water-cooling system, operated by rotary force pump.

thus raising the boiling point and, in a measure acting as a self-regulator, with consequent increased temperature of the cylinders, and increased power and economy of the engine. Other designers have attempted to fill the circulating system with a liquid having a higher boiling point than water, but few liquids have so large a specific heat or heat capacity as water and on this account such attempts, although resulting in higher cylinder temperatures, have usually failed to properly cool, not because a lower cylinder temperature was needed, but because they did not carry off the excess heat, over and above the desired temperature. Other designers again have raised the temperature of water-cooled engines by reducing the amount of space exposed to the cooling water.

Reducing the Cooled Area.—This is a very effective method and one which the designer can control to perfection.

Thus in the early Columbia, as in the several foreign engines, only the cylinder heads were water-jacketed, leaving the remainder of the cylinder to be air-cooled. Many designers have water-jacketed only the upper portion of the cylinders, leaving the lower portion exposed to the full measure of heat. Still others varied the amount of water-jacket, according to the needs of the particular portion of the engine, making it more around the exhaust valves and less at other less heated points. This arrangement, used for many years on the Duryea three-cylinder, 4 cycle engine, gave excellent results, maintaining the cylinders at a very high and economical temperature, which has been seldom exceeded, while enabling the use of light and small constructions in general. In these engines, as in many others, the cylinder heads were removable and were not water-jacketed, but the jackets extended well above the compression space and formed a cool support for the heads, which were screwed into place like pipe plugs.

Water-Cooling Systems.—The general subject of cooling is easily understood, and may be compared to the circulation of water from the water-front of a kitchen stove to the kitchen boiler, and back again. The water stored in the radiator is cooled by the air, and, as it cools, it settles, because of its slightly increased density, toward the bottom of the radiator, while the water in the cylinder jackets, being warmed by combustion in the engine, rises and flows toward the top of the radiator.

Upward Inclination of the Water Circulation.—It is to be understood, of course, that the radiator is usually higher at its top than the heads of the cylinders, while the position of its bottom is not a matter of much consequence; also that suitable pipes, extend from the bottom of the radiator to the water-jacket, and, from the top of the water-jacket of the cylinders to the top of the radiator, *preferably rising from the one to the other.* The reason for this upward inclination is easy to understand. If the top pipe does not have a general upward direction from the cylinder jackets to the radiator, there is danger of steam gathering in the highest portions, and interfering with the circulation by crowding the water back toward the jackets. If, however, the radiator outlet end of the pipe is the highest, then this steam passes to the radiator, where it is cooled and condensed or where, if excessive in quantity, it may escape through the vent or overflow pipe.

Cause of Water-Circulation.—While generally speaking, the circulation of the water is believed to be caused by the presence of steam bubbles, which, combined with the water, form a column much lighter than the column of cold water in the radiator, and, therefore, rapidly moving to the highest point of the system, and permitting the cool water

rom the bottom to flow in, yet, as a matter of fact, this ame action takes place in the presence of hot cylinders, vithout the formation of steam. While the water itself xpands slightly, if heated above 39 degrees F., and, thereore, tends to act as above stated, one of the principal causes of motion in this case is the presence of small particles of ir in the water, which expand very considerably, as the vater is warmed, and thus change the weight of the respecive columns, because of this expansion and change of denity. A familiar example of the expansion of the air contained n water is seen in the air bubbles clinging to the inside of he water pitcher, or even in a glass of water, which has tood quiet for some time, so as to permit the air contained n the water to expand and gather into visible bubbles, beause of the warming of the water by the heat of the room.

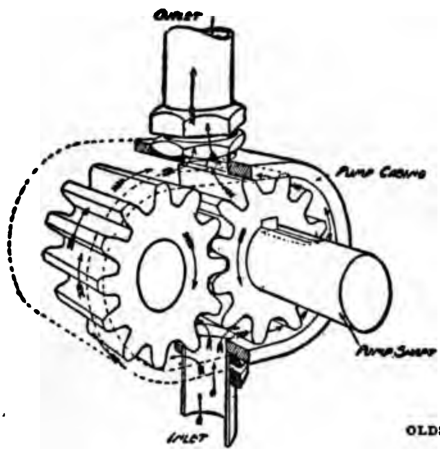


Fig. 20b.—Sectional diagram of a typical gear pump used in waterooling systems. The gears rotating as shown by the arrows carry the iquid up the sides of the case, thus compelling it to rise through the utlet at the top.

Natural Circulation or Thermo-Syphon.—The natural irculation of water, as here described, is usually termed "thermo-syphon" circulation, although other terms such s "gravity" circulation, are sometimes applied. It is the implest and most satisfactory water circulating method, lthough it requires somewhat larger pipes and larger radiator han the forced circulating systems hereafter described. These larger pipes, however, add some cooling surface and re not objectionable from any point of view, except that of lightly increased cost and weight. The use of natural cirulation is undoubtedly growing, particularly in the lighter

cars, where both simplicity and low cost are essential. The slightly increased amount of water carried in such systems insures a wider range of action than is possible with the smaller quantity in force-pump systems, particularly when the engines are worked hard enough to cause the water to boil and pass away as steam.

Advantages of Natural Circulation Systems.—The great advantage of the natural system is that the water circulates very slowly when the engine is cool, and with increased rapidity, as the amount of steam increases and lightens the column of water passing to the radiator. No mechanical circulation system secures this advantage, because the speed of the pump depends upon the speed of the engine. Thus, an excess of water is probably pumped when the engine is running under light load at high speed, while, on the other hand, probably not enough is pumped, when the engine is laboring under heavy load at slow speed.

Reasons for Preferring the Pump Method.—However, many designers give preference to the pump method of circulation, which includes in such a system as above described, a pump usually placed in the lower pipe, so as to take the cool water from the bottom of the radiator and force it into the water jacket. This pump is driven in any convenient manner from the crank-shaft or cam-shaft of the engine, and several varieties of pumps are used, as will be described under proper heading.

The Auxiliary Fan.—In addition to the use of the radiator and water circulating system, either natural or by pumps, an air-circulating fan, is usually placed directly behind the radiator and in front of the cylinders of the engine. This location of the fan draws the air through the radiator, and thus causes it to cool its water much more rapidly than would otherwise be possible. The fact that this air is thrown past the cylinders is of small moment, because it is not exceedingly warm after leaving the radiator. This fact becomes evident, when one considers that the temperature of the water in the radiator cannot exceed 212 degrees F. and is generally much below that temperature.

Average Air and Water Temperature.—Assuming that the water from the cylinder jackets enters the radiator at approximately the boiling point and leaves it at about 100 degrees, it is evident that the average radiator temperature is only about 150 degrees, or possibly less, because of the rapid cooling near the top of the radiator and the much less rapid cooling near the bottom. Consequently, the average temperature of the air on leaving the radiator would be considerably less than 150 degrees, because not all particles of air in passing through, take up the radiator temperature. This temperature of 150 degrees, or less, is not hot as com-

pared with the temperature of the cylinders, so that even this air, when thrown against the engine by the action of the fan assists in cooling it. On this point there is much misconception among engine-users, many of whom imagine that a cool engine must be one which feels cool to the hand, whereas such a temperature is very far below the one which gives good results.

Water and Other Cooling Agents.—Many designers have sought to use some cooling medium, which will not maintain a temperature, as low as does water. Such mediums, however, are very expensive, troublesome, or objectionable from other points of view, beside that of the boiling point alone. Oils, for example, some of which have lower boiling points than water have been frequently substituted, particularly in winter time. If the oil boils and its vapor escapes there is an appreciable financial loss, whereas the loss of more or less water is of no consequence. Generally there is more or less leak from any water-cooling system, and the water quickly evaporates, leaving no damage nor objectionable result; but oil leaking is objectionable from the filthy floor it soon produces and is more dangerous in case of fire. Other mediums than oils have been tried, some of which have been quite ingenious. Thus one inventor fitted his engine with sealed tubes containing alcohol or light, easily-volatilized liquid, which ordinarily rested in the lower end of the tubes forming the cooling jacket. The heat of the engine, vaporizing this liquid, caused it to pass to the upper ends of the pipes, where, exposed to the cool air, it condensed and fell to the bottom to repeat the process. This was a very rapid and reasonably satisfactory method of cooling, objectionable principally from the point of view of the increased cost involved.

CHAPTER XXI.

AIR-COOLING.

Of the Conditions of Air-Cooling.—Having recognized the advantage of high wall temperature and the economy resulting therefrom, the reader will more readily appreciate the value of air-cooling, which consists in simply exposing the hot cylinder walls to a more or less rapid current of air, and permitting this air to absorb the heat direct, instead of through the medium of heated water. The earliest air-cooling systems were fitted to engines of rather small size, such as the motorcycle engines of the present day, and consisted, generally, of metal flanges or ribs cast on the outer surface of the cylinder, so as to greatly increase the surface exposed to and cooled by the air. Later these cast flanges were replaced by attached flanges of bronze or copper, usually forced down upon the cylinder, the thought being to secure a greater amount of surface, a lighter weight and generally better result.

Various Air-Cooling Devices.—One of the earliest American makers used an air-cooling system consisting of threaded spines screwed into the walls of the cylinder; tapped holes being first made thickly over the cylinder surface. This system added considerable expense, and, while the threaded spines exposed much surface, affording an efficient method of cooling, they required a thick wall for their reception, which was objectionable. The system was finally abandoned. Other makers have experimented with other means, one of which consisted in fitting the outer surface of the cylinder with smooth, shallow-depth cylindric holes, into each of which a tube of copper was placed, being secured by forcing a steel ball into the bottom end of the tube and thus expanding it tightly into the hole. Such a method of holding copper in an iron or steel fastening is found objectionable, generally because the copper expands and contracts under temperature variations more than does the iron, and

finally loosens; with the result that the efficiency of the system is destroyed. Still another method employed short spines, cast integral with the cylinder, which was then surrounded by an air-conducting jacket, through which air from a blower was delivered; this air, passing in close contact with the cylinders and the short spines, carried away the heat. The more or less objectionable and expensive jacket or conduit, together with the necessary blower, seemed to be against this system. However, one of the latest and most successful systems employs a modification of this idea, in which the large fly-wheel is provided with turbine vanes, forming a sirocco blower, which exhausts the air from the engine housing. This housing is provided

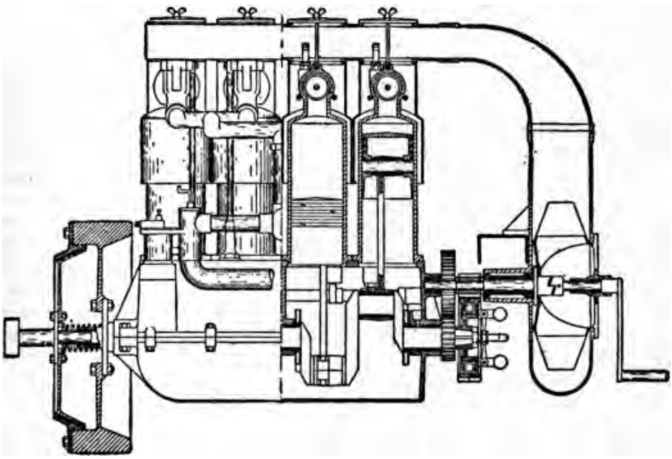


Fig. 21a.—The Frayer-Miller cylinder-cooling system. Air is forced through an "air jacket" from the blower at the front of the engine, circulating and absorbing the superfluous heat.

with a partition below the top of the cylinders, which has jackets arranged to direct the air along their sides. The air, admitted above the horizontal housing partition, strikes the cylinder heads first, and then enters the housing proper, passing along the cylinder walls inside the cylinder jackets; thus effectually and equally cooling the cylinders. This point of equal cooling on all sides is of more than ordinary importance because the cylinder, unequally cooled on opposite sides, distorts irregularly and its piston rings cannot properly hold the working gases.

Improved Radiating Devices.—Franklin cast sheet steel ribs in the *cylinder wall,* and fitted a sheet metal tube around *the cylinder, outside* the ribs. The lower part of the cylinder,

into which the tube leads, is boxed, and from this the air is drawn by a blower-type fly-wheel. This arrangement adds no bearings, nor complication, and interferes but little with accessibility. The air enters at the head, and cools effectually. The friction and loss in moving air by suction is so much less than by blowing, that this system succeeds where the earlier systems failed. That it cools, and evenly, no one denies. Duryea grooves the cylinder wall spirally, and, with a special steel wire of lower expansion coefficient than the iron, binds copper strips, U-shaped, into the grooves. As the cylinder heats up the contact becomes tighter. The surface of the groove is between five and ten times the cross sectional thick-

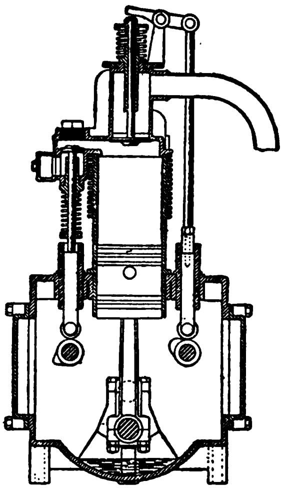


Fig. 21b.—Section of a cylinder having positively operated exhaust valve in the cylinder head. The extra area of the exhaust valve is provided for the purpose of expediting the exhaust, thus assisting in the cooling of the cylinder.

ness of the copper, so that, even though the joint be not fully efficient, the surface is so large that all the heat the copper can carry will be transferred. The strips allow free expansion, do not cause warping, and permit air to reach the wall, as well as offer more surface than is possible by other methods. So efficient is this method that the motion of the vehicle circulates all the air necessary to cool cylinders of the 2-cycle type up to 4″ diameter, thus avoiding the use of a fan.

Disadvantages of Water-Cooling.—So simple and so efficient is this method of cooling by air, that it seems destined to grow in favor. It is free from leaks found in the

water system, free from freezing in cold weather, has neither the weight nor the complexity of the water system and the engine cannot be worked beyond the cooling capacity as easily as can an engine using the water system. This point of overworking is worthy of consideration. Most water-cooled automobile engines are provided with systems capable of meeting all ordinary needs, but in extreme cases, such as unusually hard service, and the like, and in hot weather, the water may boil so rapidly that the vents, or overflow pipes, will not carry off the steam properly. Thus joints are forced open, or radiators are caused to leak, or the engine overheats and pounds, pre-ignites, loses power, and, in other ways shows symptoms of distress. In the air-cooled engine many operative difficulties may occur, but the safe operating range is usually much greater than in the water-cooled engine, for, while water absorbs considerable heat before its conversion into steam, any excess steam may act to prevent the water from properly entering the jackets, and steam itself will carry away very little heat. Consequently, the water system fails, under such conditions, because the excess steam clogs its operation.

Advantages of Air-Cooling.—With the air-cooling system this latter condition can not exist. It is, also, more or less self-regulating, because it carries off more heat, as the wall temperature increases, and there is no limit to the heat of the walls, short of the points at which pre-ignition and failure of lubrication occur. Thus, where the water-cooled system does not work above 212 degrees—because at this point the water turns into steam and steam is not a good cooling medium—the air-cooling system will work until its wall temperatures are as high as 500 or 600 degrees, or even above, so hot in fact that cigarettes have been lighted on the flanges and ordinary solder melts if placed on the cylinder heads. Yet, even with these temperatures, the engine may be working with good satisfaction. Thus, it is seen that, whereas water-cooling is limited to the boiling point of water, probably 150 degrees above an average atmospheric temperature of 60 degrees, the air-cooling system has a range of 450 or 500 degrees, or possibly more, above that same atmospheric temperature. It will thus be seen that an air-cooling system, capable of properly cooling, will increase its efficiency several times by the increased heat of the walls, and that the walls at 450 degrees will lose to the air three times as much heat, as if their temperature were but 150 degrees, assuming the air at zero. On this account the air-cooling systems do not require so large a radiating surface as do the water-cooling systems.

The Cooling Fan and its Driving Power.—In all the larger automobile engines, the cooling fan is a necessary adjunct, for the reason that the excess heat developed during operation *must be* carried away by the air, and only a *power-driven fan can* cause sufficient air to pass through the

water-cooling radiator, or through the flanges or spines on the air-cooled cylinder, and absorb the excess heat found on the hot surfaces. The application of such a fan may seem like a simple matter, but so great is the resistance of the air that the power required to drive it runs up very rapidly as the speed of the engine increases. This increased need for power renders the fan construction, its bearings and driving mechanism inadequate, unless they are very strongly designed. Thus, in some tests recently made, it is shown that a fan rotating at twice the speed of the engine required as high as six horse-power to drive it, when the engine was making 2,000 revolutions per minute; certainly a very appreciable drag on the engine, not to mention the cost of additional fuel. While this showing is perhaps exceptional, it is well known that motor-vehicle fans require considerable power, and that they throw a needless amount of air at high engine speeds, on account of the fact that they are necessarily geared high, in order to be able to cool the engine sufficiently, when it is pulling hard at slow speeds.

Methods of Driving the Fan.—This unexpected showing on the amount of power required to drive the fan accounts for the failure of many of the earlier fan-drives to do their duty. It also explains why the twisted belt or small rope, then often used, wore out quickly, and failed to drive the fan positively. Were it not for the burning of the belt by friction, this failure to drive at a rate proportionate to the engine speed might have been beneficial, but high speeds soon destroy a belt by friction, if much slipping takes place. On this account, positive drives, like chains or gears, were introduced, and often found objectionable, because the inertia of the fan, because of the great strains on the driving mechanism during sudden starts, sudden stops, or changes of speed, such as might result from pre-ignition or other causes. To overcome these difficulties, the practice of introducing either springs or friction devices has become common, the fan being thus enabled to take up the motion of the drive more easily, and thus save the strain on the parts.

Fan Shapes and Construction.—A great number of fan shapes have been used, most of them varying, however, in the number of blades, from two to eight or ten, either separate or connected at their tips by a rim. Usually the blades are attached to a hub, but in some cases the whole fan is cast in one piece, generally of aluminum, or is punched from a single disc of sheet metal, which, having a wire around its edge, forms a light and strong construction. While most of the fans in common use are of the screw or helical variety, some automobiles are equipped with fans or blowers of the turbine type, which are placed behind the radiator, and act to throw the air inward, as on a number of foreign-made cars, or are built alongside the fly-wheel, and throw the air outward.

Turbine Fans and Blowers.—As a general statement, the more common form of fan, usually having four blades, moves a larger volume of air, with a smaller expenditure of power, than does the turbine form, but where there is much resistance to be overcome, or the air must be moved at considerable speed, or the volume of air moved is not so important, the turbine form develops a much higher efficiency. In a few instances blowers of the turbine variety have been used, but these are provided with spiral cases to carry off the air, and have proven quite efficient for this service.

CHAPTER XXII.

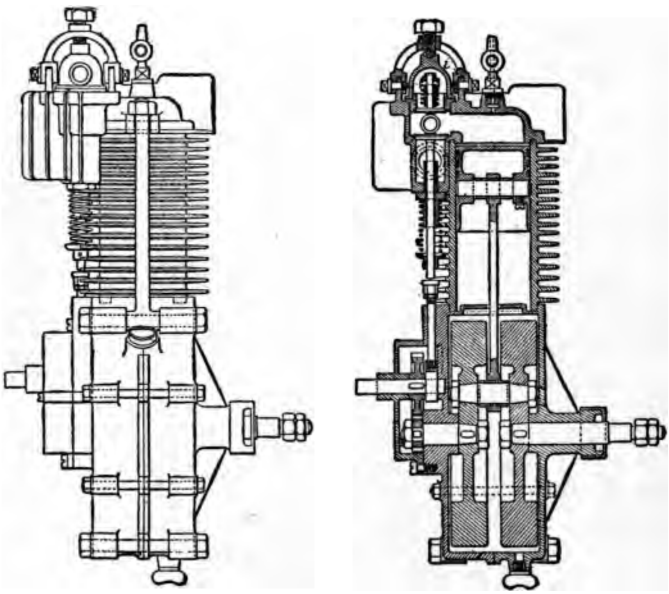
The Single-Cylinder Engine.

The Single-Cylinder Motor-Car Engine.—The usual stationary gas engine is of the single-cylinder variety, and the earlier automobiles were fitted with perfectly similar designs, because there was no other practice to follow. Periodically since the early days, the single-cylinder car has been offered to the public, largely because it can be made with fewer parts to look after and keep in repair than can an engine of more cylinders, and, also, because, for this reason, it appeals to the buyer who is doubtful of his mechanical ability. In short, simplicity of structure and low cost of maintenance constitute its claim to value. Where a single small cylinder is enough to do the work, it still finds users, and, accordingly, most motorcyclists find it very satisfactory.

Advantages of the Single-Cylinder: Economy and Simplicity.—So long as the parts of a mechanism wear out and give more or less trouble, just so long will the public very properly appreciate simplicity—and the single-cylinder engine is certainly simple. It has the fewest parts possible in an engine of its design. Nor is simplicity all. Having the fewest parts, it has less total friction; because it has but one piston, one set of valves and one set of bearings. In proportion to its cubic contents, it has less cylinder wall than a multiple-cylinder engine of the same power, because the amount of wall needed to enclose a given quantity of gas is least when the enclosure is of spherical shape; and it is certain that two cylinders less resemble a sphere than does one. So, all things considered, it is easily seen why the single-cylinder engine is more economical from the users' standpoint, as well as from the point of view of the maker.

Disadvantages of the Single-Cylinder: Vibration.—The single-cylinder has its serious defects which must render it always unsuitable for motor vehicle use, except when excep-

tionally well designed, as in the Brush or Cadillac engines. Its worst defect is its vibration. This is due to the difficulty of balancing the moving parts, also to the fact that, in the usual 4-cycle form, where the impulses are few and far between, they must be of large size, in order to furnish the power required. Daimler is called the "father of automobiling" in Europe, not so much because he anticipated Benz, and others, in applying the gas engine to vehicle propulsion, but because he foresaw the value of the small-sized engine, and developed it. At the start, he used the single-cylinder



Figs. 22a. and 22b.—Exterior elevation and cross section of a single cylinder air-cooled engine showing cooling flanges, built-up crank shaft, with two fly-wheels, automatic inlet valve, etc.

engine, and endeavored to make it suitable to his purpose by keeping it small, and by running at such high speeds that, even though it had three idle piston strokes to each working stroke, it could maintain a fairly even delivery of power, the strokes coming so fast that there was very little loss of time between them. This high speed permits the use of a light and small fly-wheel, as may be seen on the motor-cycle motor of today; so small, in fact, that it may be and often is, enclosed in the crank case. But, unfortunately, high speeds will not destroy operative vibrations, although they permit the

use of a smaller engine, and, by virtue of their rapid succession at high speeds, they largely neutralize one another.

Devices for Neutralizing Vibration.—By the use of counterbalances on the fly-wheel, it is possible to lower the vibratory effect, but not to destroy it, unless considerable complication is added. Thus the early Wintons were fitted with a heavy sliding bob-weight driven by an eccentric from the crank-shaft. This heavy weight, moving at slow speed, largely balanced the piston of lighter weight, but with greater speed, due to its longer stroke. A later example of design along this line is seen in the Brush engine, in which there is a set of gears meshing together, and, of course, revolving in opposite directions. One of these is attached to the crank-shaft and fly-wheel, while the other carries weights which largely balance the connecting-rod and crank-pin. Since these wheels move in opposite directions, the bob-weights move crosswise, when the crank-pin moves sidewise, and down, when the crank-pin moves up; thus offering a very fair working balance to the crank-pin and part of the piston weight. But there still remained a part of the piston weight which was not balanced by the revolving bob-weights. Consequently, this attempt, while better with reference to the crank parts, was not so good for lessening the piston vibrations, as was the Winton bob-weight, already mentioned.

Power-Impulse Vibrations.—Even if the moving parts of the single-cylinder engine could be balanced, there would still remain the impulse balances to be considered. It is evident that, at each power impulse, there is as much pressure against the cylinder-head as against the piston-head. Thus, the engine would be pushed one way, as far and as fast, as the piston is pushed the other, except for the fact, that the engine body is fastened to the mass of the vehicle, while the piston is attached to and propels the crank-shaft and fly-wheel. It may be seen, then, that, although there is as much pressure against the cylinder-head as against the piston-head, and that the mass of the vehicle tends to hold the engine steady against the effect of the impulse, still it is impossible to avoid the impulse, which tends to vibrate the vehicle. As the piston is driven downwards in a vertical single-cylinder engine, it accelerates the fly-wheel and mechanism, which, in turn, carry the power to the rear wheels.

Lifting Tendency of the Impulse Reaction.—This effort to turn the wheels, so as to propel the vehicle forward, causes their forward portions to be forced downward, and, by an equal amount, lifts the forward end of the vehicle. A little thought will show that, if the wheels could not turn, and the engine was powerful enough, the front of the vehicle would be raised in the air, and would revolve backwards around the axle. So it is evident that each impulse acting on the piston tends to raise the front of the vehicle. Thus, while this im-

pulse is acting on the piston and forcing it down, it is also reacting on the cylinder head with a distinct lifting effect, which, because the cylinder head is fastened to the engine mass and to the front of the vehicle, tends directly to lift the front end of the vehicle. On this account, no matter what the means for reducing vibration by balancing, the front of a vehicle using a single-cylinder engine will be lifted by the double effect above described. This makes plain the fact that, no matter if the mechanical parts are balanced, the impulses must also be taken care of, in order to achieve a quiet-running machine.

Double-Piston Engines Useless.—Recognizing this fact, some designers, such as Gobron-Brillie, have tried to balance the single-cylinder engine by fitting into the cylinder two pistons, which would move in opposite directions at each impulse. Aside from the fact that such a construction permits a very slow piston speed, there is nothing in its favor. The second piston would add its lifting effect to that of the first, and, while the speed of the lift would be less, the power of the lift would be greater. The second piston balances the first, however, so that such an engine can be in perfect mechanical balance. That the impulse action and reaction are taken by two pistons, instead of one impulse on the cylinder head, as above described, may seem to indicate that the engine has good impulse balance also, but such is not the case. Both pistons work together in producing power, and the effect on the vehicle is the same as if one piston did all the work by moving at twice the speed. Thus, although it is possible to increase the piston speeds by using long cranks, this is merely a method of gearing, and gets no more power out of the engine than if the length of stroke of the single piston had been proportionately increased. On the other hand, the double-piston engine has twice as much opportunity for leaks past the piston rings, as has the single-piston engine, and is objectionable on that score; while, as may be easily seen, the cost of the two sets of pistons and connecting-rod parts is more than twice the cost of one, because of the outside complications. This device has been described because it has attracted many designers, and its fallacies are too often overlooked by the inexperienced.

Placing the Single-Cylinder in the Car.—Much thought has been given by inventors to placing the engine in the automobile body in such a position that its unbalanced impulses would be taken by the vehicle mass in the manner least liable to interfere with even travel, but this has not always been possible. In general, the vehicle resists vibration in a fore-and-aft direction better than in any other. This may be understood from the following: If the engine is vertical the springs permit every impulse to produce some effect, and if the impulses come at such intervals as to coincide with the spring-vibration periods, the vehicle acquires

a considerable motion from the unbalanced impulse vibration. If the engine is placed crosswise on the vehicle frame there is too often more or less looseness of the wheels, which permits the car to sway from side to side, and to acquire a very troublesome vibration of that description. But, if placed lengthwise in the car, there are no springs nor loose wheel-bearings to vibrate in that line, while the whole mass of the vehicle resists and steadies the engine. That the early American designers recognized this fact, was to be seen in the first cars of Duryea, Winton, Olds, French, and others. Practically all of these had the cylinder heads placed well to the rear, because it was handier to get at these essential parts if so placed.

The Best Position.—The ideal position, however, is with head to the front, because in such a placing the impulse, reacting on the cylinder heads, actually pushes the engine and vehicle ahead, at the same time that the piston, through the machinery, is driving it ahead. It is not to be claimed that this is of appreciable value, but it certainly lessens the labor of the propelling mechanism to some extent. That it is not oftener used in motor-car work is largely due to the fact that the air-cooling flanges are more efficient, if the cylinder stands vertical, and the air can get between the usual flanges freely, as the vehicle moves forward.

Constructive and Operative Difficulties.—Not only must the cylinder be large, in a single-cylinder engine, but the parts must be extra strong and the fly-wheel heavy, because there is but one impulse in two revolutions of the crank-shaft in the usual 4-cycle type of engine. Moreover, this impulse comes after a compression stroke of the piston, which has taken power from the engine and slowed the motion of the fly-wheel; and this after two idle strokes have preceded it. A worse arrangement of strokes could hardly be conceived for such an engine. If the compression stroke followed the impulse stroke the fly-wheel would lose some of the power stored in it, almost as soon as it had acquired it, and, more or less, before it had been transmitted to the vehicle, owing to the elasticity of the driving parts. The result would have been, for this reason, a much more even motion of the vehicle than is at present possible.

The Single-Cylinder Not the Best.—Some designers have tried to lessen this variation in the power effort by introducing springs between the fly-wheel and the propelling mechanism, but such practice has not found very wide favor. The fact is that all such fittings add complication, and increase the cost, so that the single-cylinder engine is not so simple in the end as at first thought, it is supposed to be. Nor does this added cost and complexity stop at the engine. *The single-cylinder* engine, for a given power, must be both *large and heavy,* and its fly-wheel must be of considerable

diameter, with the result that the propelling mechanism must be heavier, also, in order to take the power of the single impulses, and to resist the strains which a heavy fly-wheel imposes, when the clutch is suddenly engaged, or the brake suddenly applied, without disengaging the clutch. It is evident that, if four impulses can be transmitted through the mechanism in a given time, instead of one, they may be but one-fourth as powerful for a given power, or four times the power may be passed through a given shaft or set of mechanical parts. These facts, while somewhat tardily recognized by automobile builders, have largely won recognition, and explain why the engine, which delivers an impulse at each half-turn of the crank-shaft, is much in favor.

CHAPTER XXIII.

The Two-Cylinder Engine.

Origin of the Double-Cylinder Engine.—Recognizing the defects of the single-cylinder engine, and the fact that the same weight put into two or more cylinders would give the same or more power, with other advantages, automobile designers turned to the double-cylinder as the next step forward. Thus, Duryea, in 1893, built the first parallel, or twin-cylinder, block-case engine, believed to be the earliest in the world, to be applied to automobile work; while Haynes, after a year's experience with the single-cylinder, adopted the double-opposed-cylinder engine in 1895, thus originating this successful design. Both these engines were of the 4-cycle type.

The Twin-Cylinder Engine.—The twin-cylinder engine, because of its compactness, seemed to be a favorite with designers and was used by a goodly number of builders. Unfortunately, being of the 4-cycle type, it balanced mechanically, but not in the matter of impulses. Since one impulse followed the other a half-revolution apart, then skipping a revolution and a half, the effect of the two impulses was very much like that of a long-drawn-out single-cylinder impulse. There was, however, a considerable gain, owing to the fact that the impulses were but half as powerful, for a given power, as with the single-cylinder engine, and that they came twice as often. But the total gain was not a reduction to one-fourth of the violence of the single-cylinder impulses, as these figures would lead one to assume, because the impulses, following each other so closely, interfered with this regular sequence record, and gave the vehicle a sort of irregular vibration or hump which was not agreeable to the riders. Practically everyone who adopted the twin-cylinder soon abandoned it because of the lack of proper impulse balance. Like the single-cylinder, no satisfactory method of overcoming this out-of-balance seemed available and the twin-cylinder simply lost advocates.

The V-Type Engine.—Some exceptions to this broad statement exist, however, such as in motor-cycle, or similar light engines, where the two cylinders are set in the same crank plane so that both connecting-rods operate upon the same crank. This necessitates placing the cylinders at an acute angle to each other, commonly called a V-type engine. This type, while out of balance mechanically, as in a single cylinder, and, while having two cylinders and connecting-rods attached to the same crank-pin, has the advantage over the twin type of being nearly in balance with respect to its

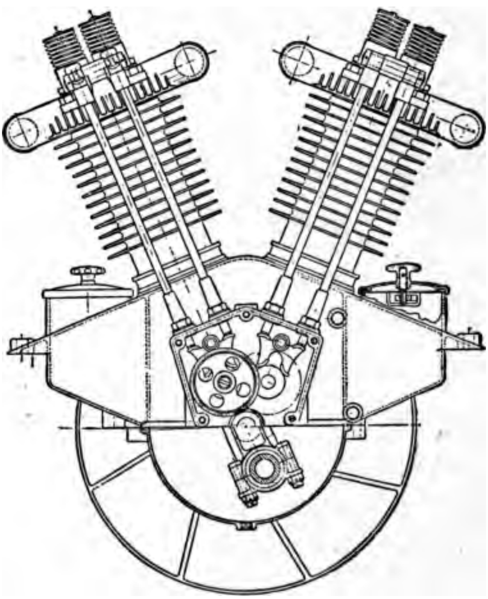


Fig. 23a.—V-shaped two-cylinder engine, showing details of valve lifts, also position of crank at extreme outstroke.

impulses, thus one cylinder ignites at one revolution and the next almost a revolution later, so that the two impulses are not exactly 360 degrees apart, but between 300 and 330, or thereabouts, in one case, and between 390 and 420 in the succeeding case, a difference which is perceptible in the running of the engine, but is not as objectionable as in the case of the twin-cylinder engine, wherein the impulses follow each other at 180 and 540 degrees apart.

Advantages of the Twin and V-Type Engines.—Whether constructed as a twin-cylinder or as one of the V-type, the

double-cylinder engine is very compact, and, therefore, well adapted to small vehicles or small spaces; further the pipes leading the gases to and from the engine are quite short, and both cylinders feed and exhaust practically alike, while the water-jackets, if any are used, are equally compact and closely connected. Further, the spark plugs, valves and similar fittings are located near each other, and may be inspected at one point, rather than at two distant points. All these advantages appealed to designers and users, and gave the twin-cylinder engine much favor among those who did not realize its objections. The twin-cylinder engine, having crank-shafts with cranks at 180 degrees, was in fairly perfect mechanical balance, and was not criticized on this account.

Balancing a Twin-Cylinder Engine.—While it is true that a two-cylinder engine of this type rocks in the plane of the cylinders, because one piston is moving up as the other moves down, it is also true that the cranks, connecting-rods, piston weights, and similar parts, balance, so far as their rotating or reciprocating effects are concerned, and the rocking effect may be largely overcome by the use of two fly-wheels, or by rigid mounting in the frame of the vehicle. While the use of two fly-wheels was an efficient arrangement, and was tried by some designers, it was not found of sufficient advantage to be worth continuing, and was not extensively used.

Difficulties with the V-Type Engine.—Aside from the difficulty of properly balancing the pistons, connecting-rods and crank of the V-type engine, it was found that the cost of machining the casting, so as to produce these cylinders at an acute angle to each other, was so great as to be against this form, as compared to that having the two cylinders parallel. The further difficulty of fitting the open ends of the cylinders to the crank-case also added to the cost. The general result has been the practical abandonment of this type of engine by most users, although still found occasionally in motor-cycle and light-car service.

The Double-Opposed Engine.—The double-opposed-cylinder engine was much more nearly perfect and was sold on thousands of machines of different makes, giving such excellent satisfaction, that it was for years the typical motor-vehicle engine. As ordinarily applied, the cylinders were slightly out of line with each other in a plane passing through the crank-shaft. This was done so that each connecting-rod might properly connect with its own crank-pin. The crank-shaft was most generally installed without a middle bearing forming a two-bearing crank, which was done partly to save cost in the crank-shaft, but more largely to get the cylinders as directly opposite each other as possible, in order that any "rocking couple" would be avoided in the engine's operation. This type of engine had the dis-

advantage of length, and was usually placed lengthwise in the vehicle, one cylinder head front and the other to the rear. Since the crank-shaft had but two bearings, and was very short, the usual practice was to place the transmission on the projecting end of the shaft by the side of the fly-wheel, thus forming one of the simplest and most compact mechanical arrangements ever used in automobile practice.

Objections to the Opposed-Cylinder Engine. — Unfortunately, however, this placing of the engine, fly-wheel and other mechanism under the body of the vehicle rendered it extremely inaccessible, which was distinctly objectionable from the user's point of view. When it is remembered that ignition troubles have always been the largest part of automobile worries, it will be seen that having one spark-plug at the rear of the engine, and another at the front, made it impossible for the user to examine both at once or to inspect the sparking of both at the same time. Further, having the timer or similar operating parts at, or near, the fly-wheel, or crank-case, made it almost imperative for the user to strip the vehicle, in order to see the whole of the engine at one time.

Carburetor Troubles.—Much the same reasoning applies to the carburetor and its piping. In the double-opposed engine the inlet valves were at opposite ends, while the carburetor was usually placed near one head, and its piping carried close to the crank-shaft, where it divided and went to each cylinder head, making a very long, and not very satisfactory, conduit for the in-going supply of mixture. It is well known that, in general, a carburetor delivers more or less liquid, which may or may not vaporize as it proceeds to the firing chambers. In the two-cylinder form this liquid was more than likely carried to the lowest cylinder. Thus, in going up hill, the rear head probably received a larger proportion of fuel than was proper, while, in going down hill, the reverse would be true. Again, in the arrangement of the piping, the liquid flowing along the under side of the pipe from the carburetor would, at the dividing point, follow the most direct wall and come to one cylinder in larger quantity than to the other—it being much easier to continue in motion in the direction started, rather than to reverse direction—and come back toward that cylinder head, near which the carburetor was located. So objectionable was this effect in many cases that some designers, like Haynes, sought to overcome it by the use of two carburetors, one for each cylinder, but this required a more accurate adjustment than most users could properly effect, and was finally abandoned.

Construction of the Double-Opposed Engine.—The two-cylinder-opposed engine used single-cylinder castings, which offered the same problems in construction that were found

in connection with the single-cylinder engine. The arrangement of the valves was practically the same, except that a single cam-shaft, lying across the top of the crank-case, was, in many cases, adopted to carry all the cams, and thus do away with the necessity for cam-gears, shafts and bearings for each cylinder. This type of engine was extremely well-balanced, both as to impulses and moving mechanical parts; and users of the vehicles could scarcely determine from the vibration the number of cylinders employed. The objections that led to the abandonment of this type of motor, very generally in pleasure service, were not the defective service efficiency, but the usual inaccessibility. Repair bills, when necessary, were needlessly large because of the difficulty of reaching, inspecting and adjusting the parts. To render adjustments easier, a number of makers constructed

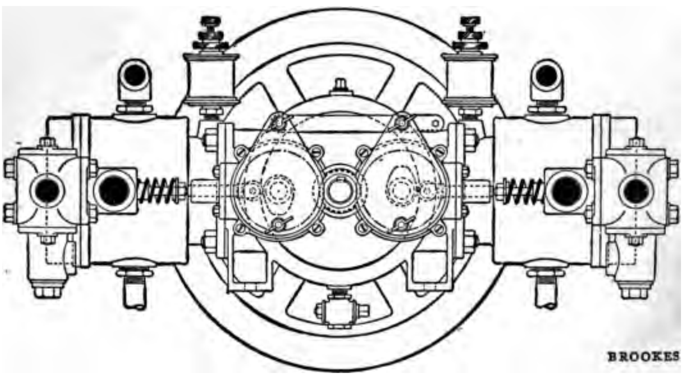


Fig. 23b.—Side elevation of a two-cylinder opposed engine; showing details of valve lifting gear and inlet and exhaust ports.

the engine with the upper part of the crank-case removable, thus permitting access to the valve lifts, cam-shafts and similar pieces, or else removing those parts with that portion of the crank-case.

The Double-Opposed Engine in Front.—The demand for greater accessibility caused engine designers to move the engine to the front. Thus, many thousand vehicles having the two-cylinder opposed engines mounted in front were marketed. These engines, however, no longer used the earlier arrangement of transmission on the crank-shaft, by the side of the fly-wheel and single chain to the rear axle, but adopted the shaft drive to transmit the power from the front of the vehicle, toward the rear axle. The practice, therefore, was to place the engine crosswise in the vehicle, one head, with its valves and spark-plug, being at one side of the vehicle

body, and the other, at the opposite side. This arrangement permitted access from the front by either removing or working over the radiator, and when the cover or bonnet was lifted the whole engine was exposed and easily reached.

Position of the Exhaust Valves.—Most early engines had their exhaust valves at least on the under side, the idea being that the products of combustion or any excess oil, carbon, etc., would escape much better if the exhaust valve was below, but, when the opposed-cylinder engine was moved to the front of the vehicle, it was the common, if not the general, practice to place the valves on the upper side of the cylinders, where they were readily accessible. This arrangement had the additional advantage of keeping the heat of the exhaust pipe and exhaust valves on the upper side of the cylinder, where it had less harmful effect, than if placed on the lower side, with consequent better cooling.

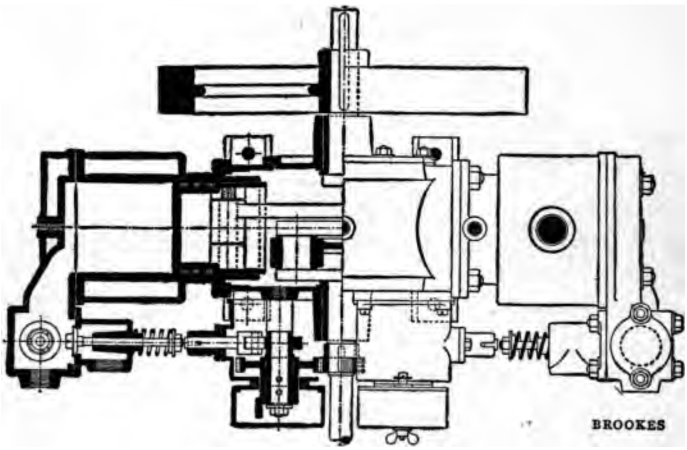


Fig. 23c.—Top view and part section of a two-cylinder opposed engine; showing section of one piston, ends of two pitmans and the common crank-shaft.

Construction of the Crank-Case.—The double-opposed-cylinder engine required practically the same amount of crank-case as was required by the single-cylinder engine, because, instead of a bottom to the case, the side opposite to each cylinder was finished, just like the first side, and was closed by having the second cylinder attached to it. In general, the cylinders were attached, as is the common practice, by cap-screws or stud-bolts, but in some instances bolts passed from one cylinder-flange, through proper lugs in the crank-case, *to the opposite* cylinder-flange, thus binding the cyl-

inders together firmly and with great strength. This latter construction permitted the use of a somewhat lighter crank-case than would have been required, had the material of the crank-case been called upon both to hold the cylinders, and to take the strain carried by the cylinder bolts or screws.

Difficulty of Proper Lubrication.—Another objection to the two-cylinder opposed type was difficulty of lubrication. The crank-shaft, revolving in one direction, very naturally threw more oil into the open end of one cylinder than into the other, because the cranks, in revolving, dipped in the bottom of the case, and then moved toward one cylinder from the bottom of the case, while, as is evident, they threw no great amount of oil into the other cylinder, because they moved toward it only from the top of the case, where they could not obtain oil. Some designers provided to neutralize this unequal lubrication by placing a baffle plate in one cylinder mouth, such a plate being slotted sufficiently

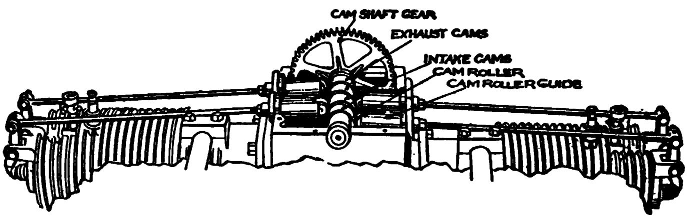


Fig. 23d.—One method of arranging the cams-shaft and valve-operating gear on a double opposed cylinder engine.

to permit the passage of the connecting-rod, while serving to catch most of the oil thrown by the connecting-rod and crank-pin, thus preventing excess lubrication in that cylinder.

Difficulty of Offsetting the Crank-Shaft.—Another objection to the opposed engine was in the difficulty of properly offsetting the crank-shaft. Because offsetting made the crank-case non-symmetrical, and carried one cylinder higher than the other—unless the whole engine was slightly inclined to make up for this—one cylinder-head would be lower than its mouth, while the other would be higher; and this irregularity would increase the difficulty of maintaining even lubrication, because the cylinder having the low head was the one on the side toward which the oil was thrown.

General Structural Details.—One of the great advantages of the opposed engine was its low center of gravity. The cylinders, pistons, connecting-rods, and similar parts, were substantially in a horizontal plane, passing through the *crank-shaft,* whereas most multiple-cylinder engines have *been placed* more or less vertically, and consequently, have

the weight carried somewhat higher. Also, as in the twin-cylinder engine, the cranks were placed at 180 degrees, so that the impulses balanced perfectly, as did the mechanical parts. Since, also, the cylinders were practically in the same line, there was little tendency to rock. In some instances designers sought to secure perfect alignment of the cylinders by bending the connecting-rods enough to properly reach the crank-pins, but this distortion of the connecting-rod gave the wrist-pin bearing a decided side-thrust toward one end of the wrist-pin, while the crank-pin bearing thrust outwardly away from the axis of the cylinders. Such construction would be permissible, if well made, but has often given trouble, and is not considered good practice.

The Two-Cylinder 2-Cycle Engine.—The foregoing remarks apply principally to the 4-cycle engine, but are partly true as applied to the twin construction of the 2-cycle type. Since the 2-cycle engine ignites a charge in each cylinder at each revolution of the crank-shaft, it is evident that a two-cylinder, 2-cycle will have an impulse in each half-revolution, and thus give a nearly continuous application of power. So smooth and perfect is the action of a good two-cylinder 2-cycle engine that its operation cannot be distinguished from a good four-cylinder 4-cycle engine. For this reason many designers believe that the two-cylinder 2-cycle engine is the future form for extensive use, because it is the simplest, most compact, most advantageous multiple-cylinder form of engine. As in the twin-cylinder 4-cycle engine, its cranks are placed at 180 degrees apart, and are mechanically in balance, excepting for the rocking effect already mentioned. While this rock may be neutralized by the use of two fly-wheels, it is not considered objectionable, and but one fly-wheel is commonly employed. One designer, Duryea, goes so far as to place the fly-wheel between the cylinders, where it becomes a sort of pivot around which this rocking effect tends to act. The result of this arrangement is that the vibration in the plane of the engine is considerably greater than would be the case if the fly-wheel were at one side, but, with light pistons and counterbalance weights on the outer crank-sides, the rocking effect is not found objectionable.

Superiority of the 2-Cycle Engine.—In the 2-cycle engine of the twin-cylinder type the impulses are so completely in balance that the operation is very quiet and symmetrical. While it is quite common to make this type of engine in a block casting, it is not rare to find the cylinders cast separately, particularly if air-cooled, as in the Duryea, Chase, and some others, and placed at some distance apart, in order to give ample room for the cooling air, and, also, to protect each cylinder somewhat from the radiation of the other. *The twin-cylinder* 2-cycle engine permits of the use of

short inlet piping, short exhaust, close placing of the spark plugs, and the other advantages mentioned in connection with the twin-cylinder of the 4-cycle type, but has not, of course, the valves and complicated mechanism, necessary with a 4-cycle engine. While it is usually placed vertically —in some cases, as the early Elmores, with the heads downward—it is not uncommon to find it placed horizontally, or, as in the light Duryea vehicles, at a slight inclination, bringing the heads some 15 degrees above a horizontal line. The object of this latter placing is to secure most of the advantages of the horizontal-head-forward position, as well as to prevent the lubricating oil from running into the heads and cause carbon deposit there.

The Opposed Two-Cycle Engine.—Knowing the success and satisfactory operation of the two-cylinder-opposed, 4-cycle engine, a number of designers have built engines of the 2-cycle type having cylinders opposite each other and using a crank-shaft of the opposed, 180-degree type. In general, this arrangement has employed a crank-case common to both cylinders, because, manifestly, nothing would be gained by using separate crank-cases in such an engine, as compared to an engine of the twin type having separate crank-cases. While such an engine will work, it is not a form to be recommended, because the transfer-ports must be accurately made, in order that they may admit the mixture from the crank-case into each cylinder equally. Even when so made, they are not likely to continue in perfect order, and, in time, the result is a faulty action of the engine. Thus, if one connecting rod wears faster than the other, that piston will open its ports earlier than the other. The result will be that much more of the charge contained in the crank-case will pass into one cylinder than into the other, and a larger portion will pass out at the still open exhaust port, with consequent loss of fuel and power, as well as the irregular action, arising from the very strong impulses of the one cylinder and the weakened impulses of the other.

The Throttling Opposed-Cylinder Engine.—Some designers have used this form and arranged so that either cylinder could be run at will by opening its transfer passage, leaving the other closed. This arrangement, in connection with a throttle to control the admission of fuel mixture to the crank-case, makes a sweet-running engine, and, if not worked beyond the moderate capacity of one cylinder, it does not necessarily involve loss of economy in the matter of fuel. In fact, when one cylinder is shut off, and the other taking part charges, the engine runs quite steadily and gives good economy. In such a case it resembles the 4-cycle engine, because it has one idle piston to one working piston, a condition found in the 4-cycle engine, which *always has* one working revolution of the crank to one *non-working*, for each cylinder employed.

CHAPTER XXIV.

MULTIPLE-CYLINDER ENGINES.

Advantages of the Three-Cylinder Engine.—While the three-cylinder 4-cycle engine has not received wide recognition, it is quite probable that future designers will accord it a much larger favor than it has ever had in the past. The reason for this belief lies in the fact that, sooner or later, the consideration of price, weight and general economy will cause makers and users to select, not that which represents perfection in luxury or is ultra-fashionable, or most impressive in appearance, but rather that which best serves their needs at a fair cost. On this account they will demand the simplest, lightest and most compact power plant that can give the good results of a multiple-cylinder engine. That the three-cylinder engine of the 4-cycle type does this cannot be denied.

The Three-Cylinder Engine and Vibration.—As already shown, the three-cylinder engine gives vibrations of approximately one-ninth the severity of the vibrations of the single-cylinder engine, because the impulses come three times as often, and are, for a given power, but one-third as large. Much the same thought applies to the impulses in operation. Being three times as frequent, they need be but one-third as powerful, and so permit the use of a much lighter mechanism. In this respect the difference between three cylinders and four cylinders is not so great as might be supposed. The striking out of eight-ninths of the vibratory effects, as in the three-cylinder engine, is getting rid of the major portion of them, and the use of still another cylinder, in the effort to get rid of a portion of the remainder, is hardly worth while. The same thought applies to the impulses, which, whether one-third or one-fourth of a given power, do not differ greatly, and, therefore, the additional complications involved in the four-cylinder engine, can hardly be considered as worth paying for. Experience has shown that the ordinary passenger cannot tell the difference between a

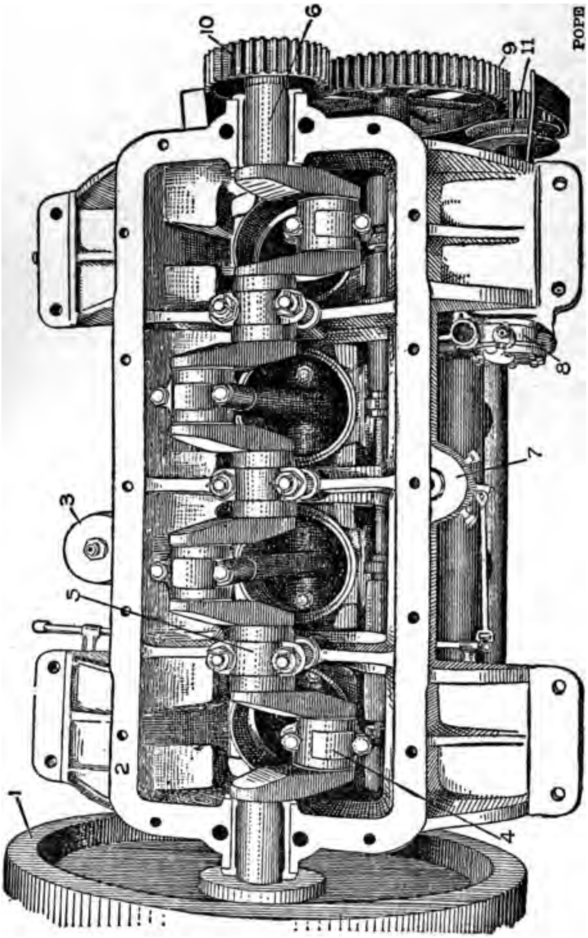


Fig. 24a.—Crank-case view of the crank-shaft of a four-cylinder engine, its bearings, cylinder ends, pitmans, and other parts assembled. Parts are: 1, fly-wheel; 2, upper member of crank-case, with brackets; 3, carburetor; 4, pitman bearing cap; 5, crank bearing cap; 6, crank-shaft; 7, commutator or distributor; 8, pump for water circulation system; 9, cam-shaft gear; 10, crank-shaft gear; 11, pulley for driving the air-cooling fan.

three-cylinder and a four-cylinder engine, in the matter of vibration, in the purr of the engine, or, by other indications; while, for all practical purposes, the three-cylinder will operate as securely and satisfactorily as does the four-cylinder, and more so, when the saving in space, in weight, in parts and in cost is taken into consideration.

Constructive Details.—The three-cylinder engine was the first multiple-cylinder engine to be cast in block, having been regularly marketed in this shape since 1897, when first built by Duryea. The crank-pins are set at 120 degrees apart, making the crank-shaft slightly more expensive than some four-cylinder shafts, but having a bearing between each two crank-pins, or four bearings in all, to the engine. The superior crank-shaft construction, with consequent long life, is apparent. The exhaust and inlet manifolds are somewhat smaller, the demand for ignition current is somewhat less, the cooling problem is somewhat easier, and, in many other ways, the engine is more satisfactory.

Three-Cylinder Balance.—In running balance the three-cylinder is as evenly balanced as any other forms of engine, so far as concerns movement in the planes of the cranks, but since, unlike the four-cylinder engine, it does not have two pistons, the one moving opposite to the other at practically the same speeds, and at the same times, it is not so well in balance in a plane passing through the cylinder axis, having a slight tendency to rock, as is found in the usual two-cylinder engine. This tendency, however, is much less than the two-cylinder, because only one piston is moving rapidly at a time, the other two pistons, at that time, moving slowly, so that the three-cylinder engine is a sort of compromise between the two-cylinder and the four-cylinder, in the matter of rocking in the plane of the cylinders. Like the two-cylinder, it can be cured of this rocking effect by the use of two fly-wheels, or by having the fly-wheel at one end and the clutch, or some similar part of the same weight, at the other end.

Block and Separate Cylinders.—While the three-cylinder engine has usually been constructed in block, it is, of course, sometimes made with separately cast cylinders, but this requires more room, and does not secure the compactness and simplicity found with the block casting. When separate cylinder construction is considered, some designers have placed these equally spaced around a single crank, but such construction is not well adapted to automobile work, because of the large amount of room required for an engine of moderate power. Thus the Adams-Farwell revolving engine used three and five cylinders around a single crank-pin and equally spaced, these revolving cylinders serving in place of a fly-wheel and giving splendid results. There was found to be ample room, however, for the larger num-

ber of cylinders and on this account the five-cylinder engine was given preference over the three. A description of this will be found elsewhere.

Reasons for Using Four-Cylinder Engines.—At present, the prevailing form of automobile engine employs four cylinders, although there seems to be no good mechanical reason why this number should have achieved a leading position in preference to three or five. The disadvantages of the twin and opposed forms of two-cylinder engines have been set forth already. Consequently, we understand that there is ample reason for employing three or more cylinders. But there is no special advantage in four cylinders over three, excepting point of keeping the cylinders somewhat smaller, with the added advantage of a larger number of impulses. The more probable reason for the adoption of the four-cylinder engine lay in the fact that it could be built by making use of patterns and tools, already on hand, for producing two-cylinder engines. Two two-cylinder engines combined produced the four-cylinder, just as two three-cylinder engines are combined to produce a six-cylinder. In other words, as the two-cylinder was formed by doubling the single-cylinder parts, so the four-cylinder was the next logical step from the builder's point of view, and, on this account, the three was skipped by most designers. The same reason applies to the five and seven-cylinder motors, which are seldom seen, sixes and eights being more common.

Advantages of the Four-Cylinder Engine.—No great amount can be said here on the advantages of the four-cylinder engine, as most of these points have been covered heretofore. The larger number of cylinders permits smaller impulses, with consequently greatly-lessened vibration, and with slight strain on the parts of the vehicle. This permits the fly-wheel, clutch, transmission, propellor-shaft, and all the various gears, to be small, while the rapid succession of power-impulses amount to a high power effort, although each individual impulse is not large. Since the suction stroke of an engine takes place during about 180 degrees, it is evident that four cylinders can pull from the same carburetor without overlapping and this is believed to insure a better carburetor action than if they overlapped, although six-cylinder engines, having overlapping strokes, are quite commonly supplied from a single carburetor.

The Exhaust Ports of a Four-Cylinder.—The exhausts from a four-cylinder engine do overlap, because the exhaust valves are opened some 30 to 50 degrees ahead of dead-center or even earlier, giving a total of from 210 to 230 degrees. This overlapping may permit some pressure from one cylinder to enter the next at the time when its exhaust valve is about to close, therefore, designers are rather careful to make the

exhaust manifold of such shape that this tendency will be largely avoided. While it is evident that, the larger the number of cylinders, the more complex becomes the problem of forming the castings, if they are made in a single block, yet so skillful have foundrymen become in automobile work, that quite intricate castings are now produced for four-cylinder and six-cylinder engines, with water-jackets, inlet and exhaust connections, plug and other openings and similar features, in addition to the regular valve ports, without involving an undue cost or a very large number of "wasters."

Block and Separate Castings.—The manufacturer very naturally prefers to handle the smallest number of parts, and the plan of casting the cylinders in a single block does much to simplify the construction, as compared with working these cylinders separately and then mounting them upon a base and attaching the various manifolds, pipes and other fittings required. While this method of manufacture is best for the maker, it is a grave question as to whether it is best for the user, because a cylinder damaged, as by scoring, may involve replacing the entire block of four, instead of replacing only a single cylinder. Screwing in a spark plug too tightly may crack a single head and similarly require replacement, although the many welding plants now in existence permit such repairs to be made at a cost much below that of even a single new cylinder, thus illustrating how the demand for a device brings about a supply.

Arrangement of the Cylinders.—In general, the only form of four-cylinder engine in common use is the one having its cylinders arranged in line, but there have been exceptions to this arrangement. The Marmon engine, built some years ago, had the cylinders placed out of line, or slightly staggered. Thus, the first and third cylinders instead of being vertical, were inclined toward one side of the car, probably 15 degrees, while the second and fourth inclined toward the other side to a similar amount. This arrangement did not perfectly balance either the impulses or the mechanical parts, but came near enough to it for all practical purposes. Being air-cooled, also, the cylinders were much better disposed to the incoming draught of air, than if they had been in line with each other. It is understood, of course, that these cylinders were cooled by air from the front of the car, thrown backward upon them, either by the motion of the car or by a fan. It is evident that, if the air is directed upon each separate cylinder by means of a suitable casing, no difference would exist in the matter of cooling, whether they were in line or not.

The Double-Opposed Type of Engine.—Other than the side-by-side-in-a-single-line arrangement, the most common form of four-cylinder engine is the double-opposed type, wherein two cylinders lie on one side of the crank-shaft

and two on the other, the engine being placed horizontally. This form, first used in the early Wintons, has of late years been adopted by a number of truck makers, and presents the advantage of keeping the engine low enough to go under the body of the vehicle, thus leaving the space above the floor less encumbered, and, therefore, better suited to truck purposes. The center of gravity of such an engine is also lower, and the engine runs with equal steadiness, if not more steadily, than does the vertical four-cylinder. The remarks concerning the two-cylinder opposed engine apply with great force to this form, since, practically, it is made by joining two two-cylinder opposed engines, so that they act upon a single crank-shaft. Such engines use, generally, a two-throw, three-bearing shaft, and are quite short in point of length of the crank-shaft. They are, however, extravagant in the matter of room because their heads project in opposite directions and, more piping is required than when the four cylinders are placed in a line on the same side of the shaft. In this form of engine, also, it is common practice to use two mufflers, and to carry the exhaust from each two cylinders into a separate muffler. Aside from the matter of keeping the weight low and saving floor space, there is a very little to commend this opposed type of four-cylinder engine, as over the more common form with vertical parallel cylinders; while, being less handy and a slightly heavier system of piping, it is, admittedly, not so good.

A Revolving Five-Cylinder Engine.—The use of a five-cylinder engine in automobile practice is not common, one American example, the Adams-Farwell, being its most prominent advocate. In this engine the crank-shaft stands vertically, and the five cylinders are placed around a common crank-case, revolving in a horizontal plane. Although the cylinders have short connecting-rods, and are of fairly large bore, they require considerable room, but a number of other advantages exist. The revolving mass serves as a fly-wheel, and thus saves some weight, these engines being quite high in horse-power in proportion to their weight. The rapid revolution of the cylinders causes them to act more or less as a centrifugal fan, and keeps a constant movement of air along their walls, with the result that they cool perfectly. It is also claimed by the makers that no muffler, or, at least, a very slight muffler is needed, because the motion of the cylinders through the air runs away from the exhaust gases, and thus does not permit them to impinge against the air so sharply and forcibly as the gases from a stationary exhaust opening; in short, that the exhaust comes from the revolving cylinder, as the gas from a rocket, rather than as the gas from a gun. However, the truth of this claim has not been vouched for.

***Disadvantages* of the Revolving Engine.**—The revolving *type of engine* is not favored by most designers, because it

is difficult to properly attend to it in operation, also because such attachments as oil cups are liable to become loose and throw off, with considerable danger to the operator; adjustments of the parts cannot be examined so well when the engine is at rest, and operative difficulties are thus rendered more obscure. It is somewhat more difficult to get the fuel into such an engine, and to get the exhaust gases away to a muffler, than in the common form; while the space required for such an engine to revolve necessitates a

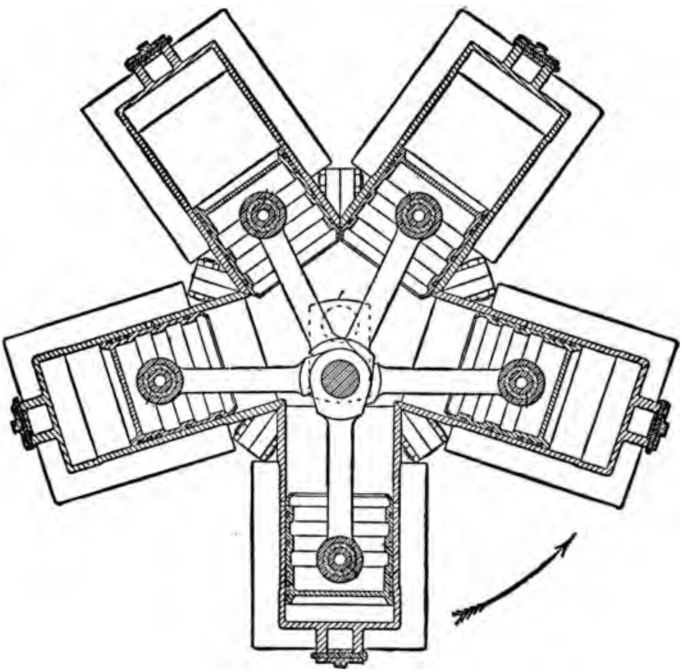


Fig. 24b.—The Adams-Farwell five-cylinder revolving engine; section showing relative position of the pistons.

horizontal position with vertical shaft and bevel gears instead of the more direct lengthwise crank-shaft connecting directly with the propeller shaft.

Advantages of the Revolving Engine.—However, one of the great advantages, of this type of engine is that the crank pin is stationary, and that, as the engine revolves so do the pistons and connecting rods, the engine revolving *around the crank*-shaft, and the rods around the crank-pin. *It will thus be* seen that there are no reciprocating parts, and

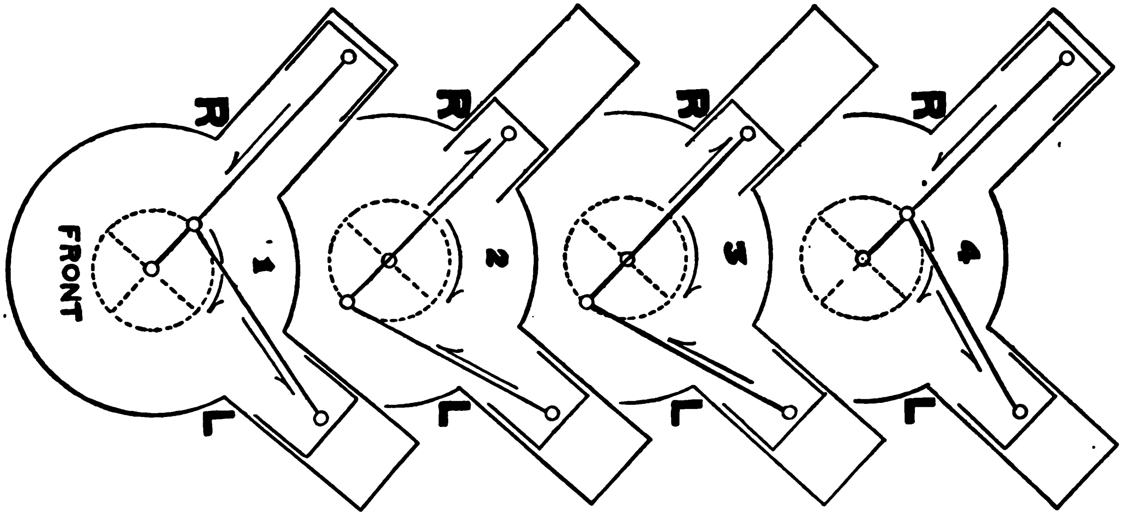


Fig. 24c.—Diagram of the cylinders, pistons and crank positions in an eight-cylinder engine, as viewed from the front of the car, when the piston of cylinder R1 is at the beginning of the working stroke. The relative positions of the other pistons, as indicated, are as follows: L1, at 90° exhaust; R2, at 1° exhaust; L2, at 90° suction; R3, at 1° compression; L3, at 90°, working stroke; R4, at 1°, suction; L4, at 90° compression. As may be understood, each of the four stages of the four-part cycle is represented at the beginning and middle of its stroke in two of the eight cylinders. The dotted circles indicate the paths of the cranks; the heavy lines, the cranks and pitmans. The arrows show the directions of movement or rotation.

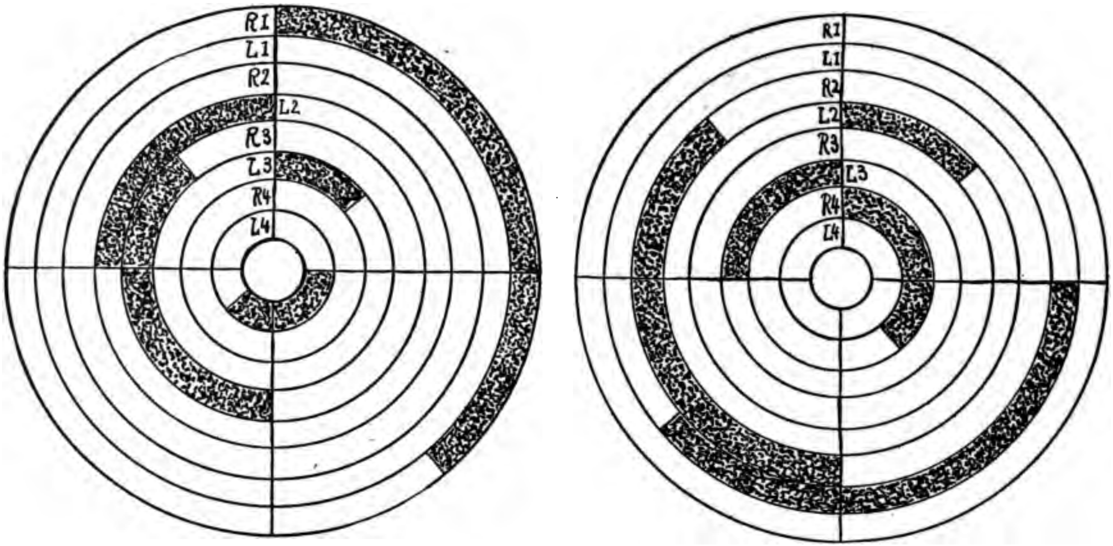
consequently, such an engine runs perfectly free from mechanical vibrations. In the engine described, throttling is effected by closing the inlet valve early or late. If closed early, a full charge is retained, but, if closed late, part of the fresh charge is expelled into a flexible bag or supply pipe arranged to receive it, and only a part is retained, with a resultant low compression and freedom from high pressures or difficult starting. Such an engine is particularly well adapted to æronautic work, because of this variable-compression feature, which permits it to be started from a standstill by the propellor of the machine, whenever there is sufficient motion to turn the propeller.

Other Types of Five-Cylinder Engine.—A number of other motors of five cylinders have been proposed, but very few have been built. Five cylinders side by side have so little advantage over four, and cost so little less than six, that the more common four or six is practically as good, and is therefore, chosen. Five cylinders have sometimes been arranged around a shaft with their axes parallel thereto, but this form of engine has not come into sufficient use to warrant a description at this place.

The Six-Cylinder Engine.—As previously specified, the six-cylinder engine doubles the three-cylinder, the two "threes" being "spiralled opposite" to one another. Thus, as recognized in practice, there are two prevailing orders of firing, as follows:

1 4 2 6 3 5 and 1 5 3 6 2 4.

In both cases the cranks are at 120° from a common perpendicular, the two middle pistons and pitmans connecting to crank-pins in one line, or at 360°. The difference in firing order is determined by the stages of the cycles to be fulfilled by the first up-coming crank-pin following the working stroke in the first cylinder. Thus, referring to the cycle diagrams on page 54, and counting two revolutions, or 720° to complete the full cycle of the engine, we see that, with the first cylinder firing at 0°, or perpendicular, as measured on the fly-wheel, the fifth fires at 120°, the third at 240°, the sixth at 360°, the second at 480°, and the fourth at 600°. Taking instead of this order, the first one given above, we find that the first and sixth cylinders fire at the same points as in the second order just described, but that the fourth cylinder fires at 120°, instead of at 600°, the second at 240°, instead of at 480°, the third at 480°, instead of at 240°, and the fifth at 600°, instead of at 120°. This involves that the lined cranks of the third and fourth precede, instead of following, those of the second and fifth cylinders. The advantages of the six-cylinder engine, as compared with the four-cylinder, are: (1) that the power impulses follow at every 120°, forty degrees before the opening of the exhaust in the last firing cylinder in every case, instead of at every 180°, or forty degrees after the *opening of the* exhaust in the last firing cylinder, thus



A B

Fig. 24d.—Diagrams of the stages of the cycle through two revolutions of an eight-cylinder engine; A, the first revolution; B, the second revolution. Showing the succession of working strokes at 90° apart. With the first working stroke beginning at perpendicular in cylinder R1, the second follows in L4 at 90°, the third in R3 at 180°, the fourth in L2 at 270°, the fifth in R4 at 360°, the sixth in L1 at 450°, the seventh in R2 at 540°, and the eighth in L3 at 630°. As may be seen, half of the working stroke in the last firing cylinder, or 50° of expansion previous to the opening of the exhaust valve, extends into the succeeding cycle, being so far contemporaneous with the power stroke in the first firing cylinder.

making the power effort more nearly constant; (2) that the power-output may be increased by one-third, without increase of cylinder diameters, and with the filling of very little more space; (3) that the vibration formerly so serious a matter in automobile operation is reduced on the ratio of 1 to 36, as compared with the one-cylinder, or on the ratio of 16 to 36, as compared with the four-cylinder. Such considerations are excellent "talking points" and matters of real importance to the builder or buyer who is seeking for the perfect engine.

Twin Multiple Engines.—The effort to produce the practically perfect engine has led several prominent builders of large cars to offer the eight-cylinder and twelve-cylinder engines within a very recent period. Although several powerful racing machines have been built in former years that were driven by engines having eight cylinders in line, the best-approved practice is to make this type on the V-shape model, for the reason that eight cylinders in line involve an unacceptably-long hood at the front of the vehicle. The V-type engine has been familiar from the beginning of the automobile industry, particularly in the two-cylinder form originated by Daimler, but was little better in point of balance, etc., than the discredited twin-cylinder engine. With the axes of the cylinders inclined at 35° from the perpendicular, and the two pitmans connecting to a common crank-pin, the power impulses followed one another at 325° and then at 395°, alternately, instead of at 180° and 540°, alternately, as in the twin-cylinder. These objections, as to intermittent power effort, vibration, balance, etc., inhere in the two-cylinder form, however, and by no means apply to the cylinder arrangement, which has been successfully applied to both four-cylinder and six-cylinder engines in commercial use.

Eight-Cylinder Advantages.—In the eight-cylinder engine the power efforts begin at every 90° of fly-wheel revolution, as shown in accompanying diagrams, instead of at every 120°, as in the six-cylinder. This involves, not only that the impulses follow one another more rapidly—thus making a nearer approach to the ideal of a constant power effort on the pistons—but also that the mean effective pressure on the crank-shaft is constantly higher, in proportion to cylinder content, stroke length, etc. Thus, as shown in an accompanying diagram, with an explosion pressure of 220 pounds, the pressure in the first firing cylinder has decreased to scarcely more than one-half before the second firing cylinder doubles it again. The pulsation is thus more nearly even, and the vibration, decreased as the square of the number of the cylinders, is as 1 to 64, compared to the one-cylinder engine, as 16 to 64, compared to the four-cylinder, and as 36 to 64, compared with the six-cylinder. Although several

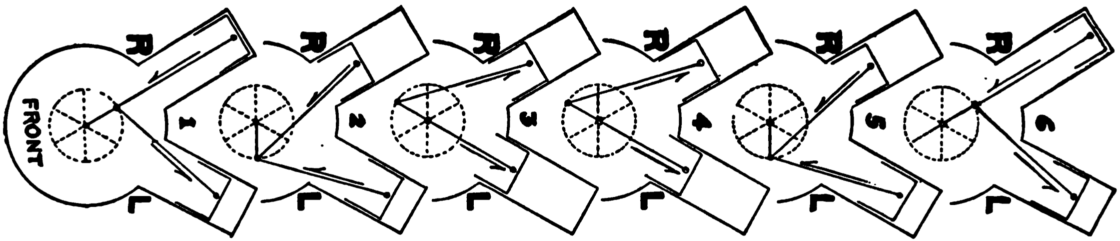


Fig. 24f.—Diagram of the cylinders, pistons and crank positions in the Packard twelve-cylinder engine, as viewed from the front of the car, when the piston of cylinder R1 is at the beginning of the working stroke. The relative positions of the other pistons, as indicated, are as follows: L1 at 120° exhaust; R2 at 120° suction; L2 at 60° working; R3 at 60° exhaust; L3 at 1° compression; R4 at 60° compression; L4 at 1° exhaust; R5 at 120° working; L5 at 60° suction; R6 at 1° suction; L6 at 120° compression. Each of the four stages of the four-part cycle is represented at the beginning, second third and third third of the stroke of 180° in three of the cylinders. The dotted circles indicate the paths of the cranks; the heavy lines the cranks and pitmans. The arrows indicate the direction of movement of the pistons.

varying firing-orders have been proposed and tried out experimentally, the practice of commercial designers favors two, as follows:

R	L	R	L	R	L	R	L	and	R	L	R	L	R	L	R	L
1	4	3	2	4	1	2	3		1	4	2	3	4	1	3	2

As in the case of the six-cylinder engine, these two varying orders differ according to the arrangement of the cranks, pitmans and valve-openings. The cylinders are arranged in pairs, their axes at 90°, inclined at 45° each from the

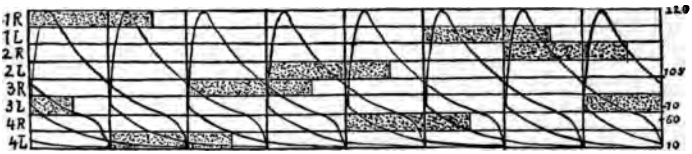
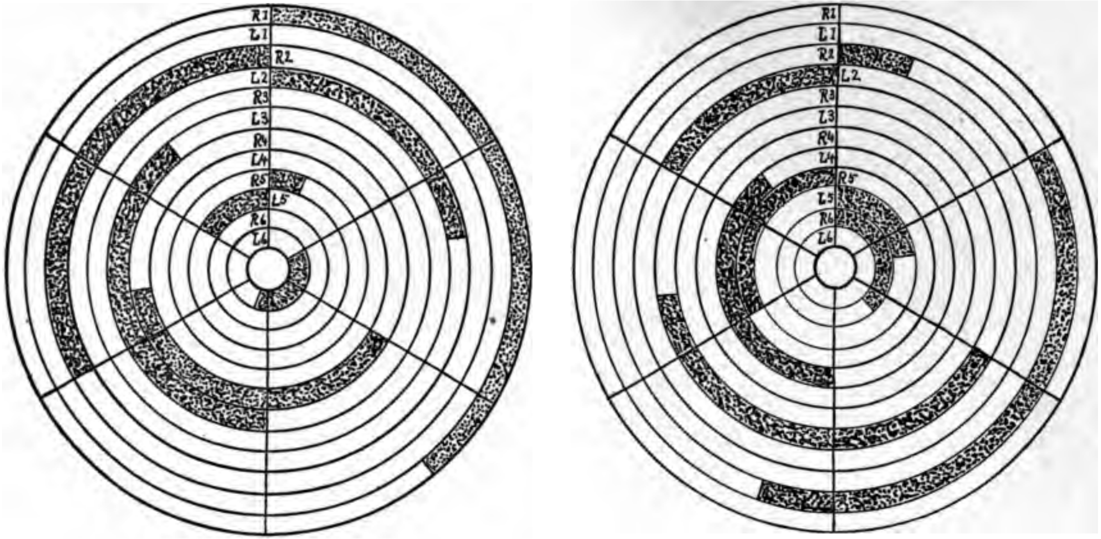


Fig. 24e.—Diagram showing the order of firing in the eight cylinders of an eight-cylinder engine, through 720°, or two fly-wheel revolutions. The letters and figures at the left-hand end indicate the cylinders in order in the right (R) and left (L) rows. The vertical lines divide the card into eight sections each representing 90° of fly-wheel rotation, and, as indicated, a working stroke begins at each such point. The superposed cylinder diagrams are intended to show the fall of pressure due to expansion, also to indicate the approximate point at which further fall is neutralized in effect by the occurrence of a new explosion. The figures at the right-hand end are intended to indicate, approximately and in general, the pressures in the cylinders.

perpendicular, slightly offset or staggered, each pair of pitmans connecting to one crank. Thus, the right-hand first cylinder (R1) pairs with the left-hand first cylinder (L1), as shown in the accompanying diagram of piston positions and cycles. The cranks are at 180°, duplicating the four-cylinder shaft. The usual arrangement with this type of engine is to set the valves and cam shafts on the inner and upper side between the cylinders, where they are perfectly accessible. The eight-cylinder requires relatively less muffler than either the four or six, demands little added complication in the oiling, firing and fuel-feeding arrangements—one carburetor being usually sufficient for all cylinders, and occupy very little more room than the four-cylinder crank-case.

The Twelve-Cylinder Engine.—Like the eight-cylinder, the twelve-cylinder engine consists of six pairs, arranged V-shaped, with their pitmans connecting to common cranks. It is, in fact, a double six-cylinder, in which, with the five-throw crank-shaft, having the cranks at 120°, the series of cycular operations begins at one extreme for the one set of cylinders, and at the opposite extreme for the other set. The cylinders are set at an angle of sixty degrees apart, or at thirty degrees each from the perpendicular. As a consequence, a firing stroke begins on each 60° of fly-wheel rota-



A B

Fig. 24g.—Diagrams of the stages of the cycle through two revolutions of a twelve-cylinder engine; A, the first revolution; B, the second revolution. Showing the succession of working strokes at 60° apart. With the first working stroke beginning at perpendicular in cylinder R1, the second follows in L6 at 60°, the third in R4 at 120°, the fourth in L3 at 180°, the fifth in R2 at 240°, the sixth in L5 at 300°, the seventh in R6 at 360°, the eighth in L1 at 420°, the ninth in R3 at 480°, the tenth in L4 at 540°, the eleventh in R5 at 600°, and the twelfth in L2 at 660°. As may be seen, 60° of the working stroke in the eleventh firing cylinder, and 120° of the working stroke in the twelfth firing cylinder, extend into the succeeding cycle, being so far contemporaneous with the next working stroke in the first firing cylinder.

tion, thus affording a much closer approximation to a constant uniform power effort than is possible with an engine of any other description. On the basis of an ideal diagram, showing an explosion pressure of 220 pounds and a normal expansion to about 60 pounds at the end of 140°, the pressure on the piston head should not sink very much below 170 pounds before explosion occurs in the succeeding cylinder. The fluctuation in the pressure is thus extremely gentle —on account of the rapidity with which power impulses succeed one another, practically negligible. The vibration of the twelve-cylinder engine is as 1 to 144, compared with the one-cylinder, and as 1 to 4, compared with the six-cylinder. The firing order of the Packard "Twin-Six" is given as

R	L	R	L	R	L	R	L	R	L	R	L
1	6	4	3	2	5	6	1	3	4	5	2

In this expression, as may be seen, there is merely a doubling of the first six-cylinder order, as given above; the right-hand row of cylinders firing in order from R1, and the left-hand row, from L6. These conditions are sufficiently set forth in the accompanying diagrams.

CHAPTER XXV.

CARBURETORS AND VAPORIZERS.

The Carburetor and its Functions.—The carburetor is the lungs of the engine and upon it depend large power, long service and efficient action. Briefly defined, it is a device for bringing air and the vapor of gasolene, or of some other hydrocarbon, into intimate association in the correct proportions to form an explosive mixture; that is, a mixture such that, if ignited, produces a combustion that is almost instantaneous. With an engine using a fixed gas for fuel no carburetor is necessary, since air and gas, adjustably proportioned, are permitted to mix on their way to the cylinder with good results. Gasolene vaporizes at ordinary pressures and temperatures, but in order that a device should deliver a sufficient quantity of mixture for the purposes of an engine, without being of prohibitive size, it is necessary that means be provided for this purpose other than simple surface evaporation.

Gasolene Mixtures by Weight.—All mixtures of gasolene vapor and air do not ignite and burn with the same degree of rapidity. A mixture too rich or too lean does not give the maximum power. To ascertain the proper proportions of gasolene vapor and air for complete and efficient combustion, the chemical composition of the substances must be considered. Ordinary gasolene contains about 84% of carbon and 16% of hydrogen. One pound of hydrogen requires eight pounds of oxygen for complete combustion, and one pound of carbon, two and one-third pounds of oxygen. Since air, by weight, is composed of one part of oxygen to three and one-half parts of nitrogen, and as the nitrogen does not assist combustion, in order to obtain one pound of oxygen, four and one-half pounds of air are required. Thus to burn a pound of gasolene, about ten pounds of air are required for the carbon and six pounds of air for the hydrogen,—a total of sixteen pounds, or about two hundred cubic feet. While this amount of air is theoretically sufficient for the purpose, it is usual in practice to allow twice this amount, owing to the fact that the nitrogen in the air has a tendency to delay combustion.

Gasolene Mixtures by Volume.—One volume of liquid gasolene to 8,380 volumes of air produces a good mixture characterized by rapid combustion, absence of odor, and no fouling of the valves. While these proportions may vary according to the properties of the gasolene and the air, a mixture containing air in excess of 10,000 parts to 1 of gasolene will not explode properly. (1 to 8,000 and 1 to 10,000 are approximately equivalent to 1.9% and 2.4% of gasolene, vapor, respectively). At the other extreme, a mixture consisting of one volume of gasolene with 4,000 volumes of air forms an explosive mixture, but if the air is reduced to 3,400 volumes, the resulting mixture will not explode.

Extremes of Gasolene Mixtures.—Mixtures of gasolene vapor and air varying in composition from one part by weight of vapor with four of air, to one part by weight of vapor with thirteen of air, may be ignited, but the greatest power is obtained from the explosion when the proportions are from one to five to one to seven. A mixture in which the elements are combined in these proportions burns quickest, produces the highest temperature, and exerts the greatest power, although the power evolved depends largely, as well, upon the degree to which the charge is compressed.

Speed of Air Movement.—In order to produce properly-apportioned mixtures for high-speed gasolene engines, the rate of flow of the air in a carburetor of the surface type should be at least 80 feet per second: in the jet type, at least 100 feet per second, which would be equivalent to 4,800 and 6,000 feet per minute, respectively. Some authorities place the figures for the jet carburetor at between 7,000 and 9,000 feet per minute.

Primary Requirements in Carburetors.—A number of facts concerning gasolene engines must be kept in mind when considering the mixing device if the engine is to give superior results. A carburetor must be capable not only of combining air and hydrocarbon vapor in sufficient amount for the end desired, but also of so controlling the composition of the mixture that the greatest efficiency is obtained under any and all conditions. As the compression pressure of the mixture varies with the degree to which the throttle is opened—thus, with the actual amount of air and gas admitted to the cylinder—it follows, for example, that, when the throttle is nearly closed, and the engine running at a low speed, the mixture must be richer than when the throttle is wide open and the speed is high. A mixture under low compression does not burn as rapidly as one highly compressed.

Requirement 1: Perfect Mixture.—The mixer must perform its function to the fullest possible extent and intimately mix the air and liquid. It is not enough that it should provide a proper mixture at high speed only, for,

although this will cause the engine to show a high power, it will not give smooth running or great power at slow speeds. If the mixture is not intimately mixed, some parts are too poor to burn, others burn slowly because lean, while other parts are too fat to burn, or burn very slowly because overfat. The result is little power, a hot engine, much deposit of soot and an ill-smelling exhaust.

Requirement 2: Correct Proportions.—In order to have full power and give the best results the liquid fuel must be properly proportioned to the air. Too much or too little liquid produces slow-burning mixtures and undesirable results. Further, although during each cycle the engine may receive the proper amount of air and liquid for the perfect mixture, if the early portion is air and the latter portion largely liquid, it is quite evident that a homogeneous mixture will not be produced and that proper ignition with perfect engine behavior cannot follow. It is therefore necessary that the air and liquid be proportioned constantly in a proper manner, and this may be rightly termed the second great requirement.

Requirement 3: Automatic Adjustment.—It is also evident that different sized engines will have different requirements, and that a mixing device suited to one may not be suitable when fitted to another. The same is true in connection with speed. A proper mixture at one speed may be completely thrown out of proportion, or may be improperly mixed at another speed. Engines nowadays run at rotative speeds from 200 to 2,000, and the perfect mixer must meet these requirements. Since at high speeds full charges are usually used, while at low speeds the throttle reduces the charge admitted, it is quite evident that the service required of a mixing device is not adequately represented by the proportion 10 to 1, but that it is probably more nearly 20 to 1, and possibly may vary as much as 50 to 1. Such wide variation increases the difficulty of maintaining proper proportions and making a perfect mixture, and renders it necessary that the mixer should automatically adjust itself to the varying requirements.

General Classes of Carburetors.—The earlier inventors generally attempted to provide the gas by drawing air in some manner through a tank containing gasolene, which permitted the air to absorb gasolene vapor and issue from the tank practically saturated with vapor. This over-rich mixture was then diluted by the admission of air to form the proper mixture. In one form wicks of cotton or even excelsior, served to distribute the vapor through the air. In another form the air was drawn down into the liquid and, bubbling up through it, became saturated. Other inventors seeking simplicity admitted the gasolene directly into the air passage, trusting that it would be sprayed or vaporized and mixed with the air before the end of the compression

stroke. Still others provided a spray nozzle, past which the air is drawn with sufficient velocity to break the liquid into a spray. This form is now in almost general use to the exclusion of other forms. Each is usually called a carburetor, but properly the gas tanks only are entitled to this name, and the present form is more appropriately an atomizer, or, since its essential service is to mix liquid fuel and air to form what is universally called a "mixture," the short, simple, expressive word, "mixer," is preferable.

Varieties in Construction.—According to these data carburetors may be divided into three classes: (1) sprayers, the type now in nearly universal use; (2) surface mixers, still found in a few cases; (3) ebullition or filtering mixers, no longer used with automobile engines. Most of the early carburetors were of the surface type, but the sprayer soon demonstrated its superiority in point of permitting a readier regulation of the mixture, as well as in superior compactness. In the original sprayer, the Maybach, the float controlling the admission of liquid to the mixing chamber was introduced. It had the familiar nozzle also, admitting the fuel in the form of a spray or jet, according to the velocity of the air passing over it in the mixing chamber, and thus formed the fuel mixture which passed into the cylinder. In spite of its defects, from the point of view of present achievements, it was a very efficient device, owing probably to the fact that it was heated by its closeness to the cylinder.

Limitations of Early Types.—Early carburetors of the surface and bubbling types could not vaporize a low grade gasolene, or deliver sufficient mixture, even with a high-grade gasolene to supply the demands of a modern high-speed engine. In the earlier types of sprayer, also, no provision was made for regulating either the air or gasolene supply, each being governed solely by the size of the orifices through which they flowed. Neither was any provision made for grinding the gasolene valve; hence an even supply of fuel of a character best suited to operating conditions was impossible. It may be said that virtually all improvements made in modern carburetors have been for the purpose of delivering a fuel mixture of the proper character to supply the engine's demands, whether for light or heavy load, or for low speeds or high.

Elements of Modern Carburetors.—Modern spray carburetors, whatever the distinctive variations in design, consist primarily of the following elements, or parts:

(1) **A gasolene inlet**, controlled by a needle valve and terminating in a nozzle, through which the gasolene is drawn by the suction of the engine piston.

(2) **An air inlet**, sometimes called the primary air inlet, through which air is drawn by suction of the engine piston,

and brought into contact with the gasolene as it sprays from the nozzle.

(3) **A float chamber,** designed to contain a cork or hollow metal float, which, because of its buoyancy, rises when gasolene is admitted to the chamber, and, either directly, or through some arrangement of levers, etc., operates to close the gasolene inlet valve to the float chamber, thus shutting off the admission of more fuel; the best results being achieved, however, when the supply is constantly equal to the demand, the level of the gasolene in the float chamber being then at all times the same.

(4) **A mixing chamber** in which the gasolene spray and the air supply mix with one another to form the explosive mixture.

(5) **An auxiliary air inlet,** through which air may be admitted as required by operative conditions to dilute the mixture which otherwise would be too heavily charged with gasolene vapor—too "rich"—to serve as a good engine fuel.

(6) **A throttle valve,** for controlling the volume of mixture flowing into the engine cylinder.

In the design and arrangements of these several parts lies the main difference between the various makes of carburetors now on the market.

Modern Surface Carburetors.—In the Surface or Puddle carburetor, air in a thin stream is passed over the surface of the liquid. The mixing chamber consisted of a U-shaped tube in the bottom of which lay a pool of liquid about one-eighth of an inch deep. The depth of the liquid was regulated by a float feed. The area of the tube was smaller above the liquid so as to increase the rate of travel of the air. The liquid being fed by gravity did not necessitate so great a suction as in cases where the liquid is drawn in by the suction. When this arrangement is working at slow speeds, the air picks up the gasolene solely by surface evaporation, but when the throttle is opened up and the speed increased, the current of air becomes intensified and sweeps away the gasolene. At the high speeds, the puddle is blown out entirely with the onrushing air in the form of spray. To secure a liquid in the tube for sure starting, the device can be primed by a rod which when pressed down, depresses the float so that the gasolene valve is opened wider. An excess of gasolene in the chamber is prevented by a drain pipe. The admission of liquid to the mixing chamber is controlled by a needle valve which may be connected by a rod and universal joints to an operating handle on the dash. Such an arrangement permits regulating the composition of the fuel to suit conditions while the car is in motion.

The Gasolene Inlet; Top Feed.—In one of the earlier *types,* the gasolene was admitted to the float chamber from *above through* an orifice which was closed as the liquid

collecting in the chamber raised the float, on the upper surface of which was secured a plug or spindle which entered the orifice. With this type, or with a similar one having the float hinged at one side, the valve being carried at a point diametrically opposite, the weight of the falling gasolene was liable to prevent the float from closing the valve at the proper time, or as rapidly as it should, with the consequence that too much fuel was often admitted to the chamber.

The Gasolene Inlet: Bottom Feed.—When the orifice is at the bottom, a system of levers may be employed to operate the valve. These levers are pivoted at one end to the float, and near their centers to the top of the chamber. As the float rises, the free ends of the levers engage with a collar on the valve stem forcing it down against its seat. In such an arrangement, the valve is closed by the buoyancy of the liquid raising the float. In the balanced float construction, the valve is closed by a weight, and opened when the gasolene level falls by the float acting on the levers, thus the float, and the valve with the weight which operates it, are balanced when the liquid is at the correct height in the chamber.

Position of the Spray Nozzle.—In the earlier types, the float and mixing chambers were placed side by side, but with such an arrangement the surface of the fuel in the chamber and in the spray nozzle would be at the same level only when the carburetor was exactly level. If the nozzle was tilted higher than the float chamber, the level of the liquid in the nozzle would be low, while if the nozzle was lower than the chamber, liquid would flow out resulting in a mixture of excessive richness. By having the spray nozzle located centrally with respect to the float chamber, a constant level is maintained in the nozzle despite any tilting of the carburetor. With this arrangement the quality of the mixture is uniform instead of being alternately too lean or too rich. Proper balancing of the float prevents breaking or disarrangement of the needle valve spindle and consequent trouble with the gasolene supply.

The Primary Air Inlet.—A wide variation from the general design is impossible in the primary air inlet, although its size may be determined by the designer, who considers the requirements as to speed, cubic intake capacity and other operative conditions. The opening has been arranged to face downward, upward or to one side, and is usually supplied with a screen of wire gauze to prevent dust being drawn into the carbureter and thence into the engine cylinder. In some cases a shutter has been provided to regulate the amount of air drawn into the mixing chamber. The latter may be operated by hand.

The Float Chamber and Float.—In the early forms of carburetor, also being the typical arrangement, the float

chamber was cast separately and connected to the mixing chamber by a tube to the nozzle. In very many modern types the float and mixing chambers are cast integrally; frequently the two being concentric. The concentric arrangement of the two chambers is growing in favor, although many manufacturers still adhere to the older design, which has them side by side. Among the latter may be mentioned the Locomobile, Peerless, Saurer, Stearns, Daimler, Decauville, Benz, and some others of more or less note.

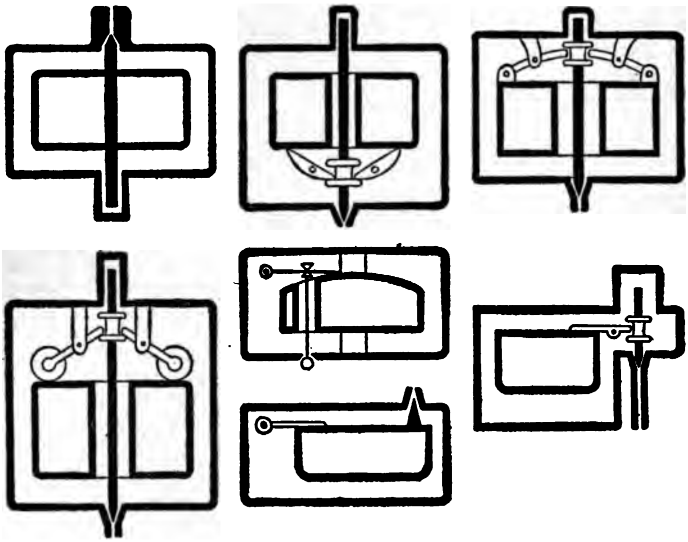


Fig. 25a.—Seven typical forms of float and valve control for the float chamber, beginning with the earliest Maybach type with the needle valve carried on the top of the float and closing an overhead inlet port; also several forms of lever lift arrangements, hinged levers and floats for annular, or concentric floats.

The Operation of the Inlet Valve.—In the earliest float-feed devices the pin valve was attached direct to the float, and closed the inlet port, as the float rose with the level of the liquid within the chamber. Such arrangement, however, failed in many cases to properly protect the needle from injury—bending, etc.—due to sudden jerks. Consequently, it failed to fulfil the function of a valve, and properly close the port. This consideration led to the introduction of the lever arrangement in its various forms, which enabled the float to actuate a separate needle valve, without communicating to it any of the jarring and shocks encountered in travel. The typical arrangement for such levers in the earlier carburetors included two levers of the first order.

bearing at one extremity upon the valve spindle, the opposite ends being actuated by the rising or falling of the float, so as to open the inlet port. Such an arrangement of double levers involved, of course, that the valve spindle should pass through the center of the float, which was perforated to receive it. In later carburetors, particularly such as have the float and mixing chambers concentric, a single lever is arranged at one side of the float, its one arm bearing against the top of the float, the other arranged to actuate the valve spindle, closing the inlet with the rising of the float. In some such arrangements the lever arm is attached to the float, with others it merely bears loosely against it. In some cases of the side lever arrangement the gasolene valve is seated by a spring, being unseated as the float falls through the action of a pivoted lever which lifts the valve, as just explained.

Valve-Closing Levers.—The double-lever arrangement was presented in two general forms: (a) where the levers bore against the top of the float, or were pivoted there, and (b) where the levers were arranged beneath the float, being actuated as it fell. In the Mercedes carburetor the lever arms were pivoted to lugs projecting from the inner surface of the float chamber cover, the ends projecting toward the center of the cover engaging with a collar on the valve spindle, so as to be raised or lowered with the rising or falling of the float. Among other makes of carburetor which have employed a similar arrangement may be mentioned the Phenix-Daimler, the Argyll, the Benz, the Peerless and the Zenith. Other double-lever valve-lifts have the levers similarly arranged beneath the float, the valve being seated by a spring or by a weight on the spindle, and lifted when the float bears against the upward extending free ends of the two levers. Of this type the Languemare carburetor is the best known.

The Mixing Chamber.—Most modern carburetors have the mixing chamber constructed on the principle of the so-called "Venturi tube," which consists of a strangled section produced by joining two hollow cones at their apices; the object being to increase the speed of the gas in passing through the strangled section. This construction may be produced either by boring the chamber in the shape indicated, or by inserting a ring in the mixing chamber, near the nozzle, to make the passage smaller at that point.

The "Venturi Tube."—If the bore of the mixing chamber was cylindrical in form, the suction of the engine might be sufficient to cause a comparatively rapid flow of the air at moderate or high speeds, but the rate would be entirely too slow to give the best results on the slow speeds. With the constricted passage, the rate of flow is sufficiently high on the slow speeds, and on the higher speeds, if the passage by reason of the constriction should be too small to admit a

sufficiency of air the auxiliary air valve opens and admits air to supply the deficiency. This valve is held to its seat by a spring the tension of which is adjustable.

The Straight Tube.—Designers of mixing chambers have sought to provide as direct a route as possible for the mixture between the mixing chamber and the cylinder. Turns or corners in the passage not only retard the flow of the mixture but conduce to condensation of the fuel. The prime requisite in regard to the float chamber is that it should be such that when the liquid is at the correct level in the nozzle, the supply should shut off.

The Spray Nozzle.—Considerable variation is to be found in the design of the spray nozzle, particularly with respect to the orifice through which the gasolene flows. Several devices have been introduced either for (a) facilitating the formation of spray which mixes readily with the air, and (b) enabling a greater or smaller flow of liquid as required by the demands of travel. These two needs of the modern gasolene engine are supplied by needle-valve regulators in the single nozzle, and by double nozzles.

Design of the Nozzle Aperture.—The form of the nozzle aperture varies widely. In its simplest form, it is merely a small hole through which gasolene flows in a stream like water out of a hose. In other cases, the gasolene escapes in a number of minute streams, instead of in one large stream, which are more easily broken into spray and more readily taken up by the air. Such an arrangement, however, is more susceptible to clogging, as the small passages are blocked completely by particles which would pass freely through the larger opening.

The Nozzle Valve.—In the earlier models of spray carburetor there was no provision for regulating the orifice of the nozzle, hence of the size of the jet. The sole regulation furnished with these devices was the variation of the size of the air inlets. The need for more precise adjustments, however, to meet the needs of the modern high-speed engine has occasioned the introduction of the needle valve regulator for the spray nozzle. Some models of well-known carburetor still have no such adjustment. Among such may be mentioned the Phenix-Daimler, Peerless, Locomobile, Stromberg, Argyll, Saurer, and Zenith. In general, the nozzle regulation is by (a) a needle or plug-shaped piece extending into the opening of the nozzle from above, and advanced or drawn away by a screw spindle, or (b) a needle valve extending upward in the nozzle tube, and similarly moved in either direction by its threaded spindle. The former type of adjustment is used with recent models of the following: Kingston, Holley, Chapin, Breeze, Benz, Wildi, etc. Among those having the latter form of adjustment may be mentioned the Schebler, Pierce, and Longuemare.

Nozzle Adjustments.—With an adjustable needle valve on the gasolene supply and an adjustable auxiliary air valve, a great variation in the quality of the mixture is obtainable. While these devices may be adjusted so as to give good results for a considerable period, re-adjustment is occasionally necessary on account of variations in the temperature of the air. Mixtures for low and moderate speeds are best regulated by adjusting the gasolene valve: for high speeds, by adjusting the tension of the auxiliary air valve spring so that the valve will lift more or less as required.

Position of the Spray Nozzle.—The common practice is to place the spray nozzle vertical in the axis of the mixing chamber. In a few cases, however, while the position is virtually the same, the tube itself is inclined, so that the jet meets the current of air at an angle. Among carbureters having this construction may be mentioned the Schebler.

Double-Nozzle Adjustment.—With the double nozzle or multi-jet type of gasolene feed two separate nozzles are provided to supply the gasolene required for the extra drafts of the engine. There are several different devices for using the double nozzle. In the Zenith carburetor a double tube is employed, one within the other, so connected with the gasolene supply in the float chamber that at low speeds, when the suction is insufficient to draw gasolene through the principal or outer tube, the supply is drawn entirely from the smaller, or inner tube. At highest speeds both may be in commission. In several models of carburetor the two nozzles extend into two separate chambers, each with its separate air supply valve, so adjusted that the small suction of low speeds is sufficient to open only one valve, thus drawing gasolene from one nozzle only, but that the greater suction of high speeds suffices to open both, calling both jets into action. Among such may be mentioned recent models of the Stearns. The Fiat carburetor also has two separate chambers, but controls the action of the two nozzles by a rotary valve, which may close the auxiliary nozzle, until the need of higher speeds demands that it be brought into action. In recent models of the Stromberg carburetor a secondary nozzle is normally held closed by a plug and spring, being opened, when the greater suction of high speeds opens the auxiliary air supply valve. In the Saurer carburetor a clack valve regulates the action of the two jets. At low speeds the current of air passes around it calling only one jet into play; at higher speeds the clack valve opens vertically, allowing both to act, and thus drawing a full supply of gasolene. The Lewis carburetor, an English instrument, has a perforated mushroom valve held over the mixing chamber by a spring. At low speeds the air drawn through the perforations is sufficient to supply the engine with fuel from one nozzle, but at higher speeds the valve *is raised, bringing* both into action.

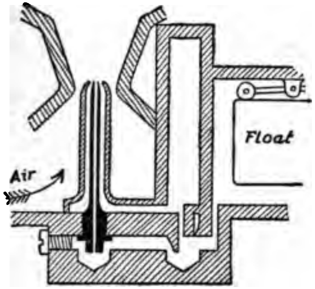


Fig. 25b.

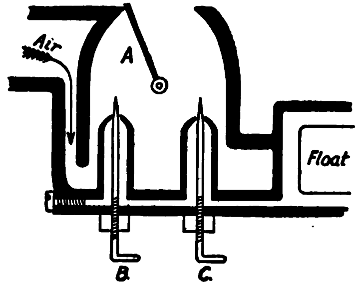


Fig. 25c.

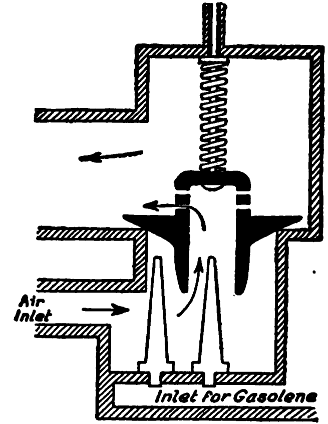


Fig. 25d.

Fig. 25b.—Double nozzle arrangement of the Zenith Carburetor. Here the two nozzles are concentric, the outer tube giving spray when a higher suction is exerted.

Fig. 25c.—Double nozzle arrangement of the Saurer Carburetor. Here B is the auxiliary nozzle, C, the common service nozzle, B coming into action only when the larger suction of the piston raises flap valve, A.

Fig. 25d.—Double nozzle arrangement of the Lewis Carburetor. The right hand nozzle is for common service, the left hand nozzle for use when the enlarged suction of the engine piston raises the mushroom valve against the tension of the spring.

The Auxiliary Air Inlet.—The auxiliary air inlet and valve has been made in a multitude of variant forms. So far as concerns the operation of the valve, however, there are two general methods employed: (1) the increased suction of the engine at high speeds acts to open the valve, which is normally held closed by a spring, or, where a ball valve is used, by gravity; (2) the throttle and auxiliary air valve are mechanically connected, so that they are opened together. The former of the two seems to be the prevailing type of valve for this purpose, and the usual arrangement seems to be to admit the extra air into the mixing chamber past the nozzle, so that the rich mixture is diluted as it passes into the cylinder. On one or two makes of carburetor, the auxiliary valve opens into the chamber behind the nozzle, or an extra nozzle is brought into action. The valve is usually of the mushroom variety, and is held to its seat by a spiral spring around its stem. In one make several such valves are arranged concentrically, each one with its own spring, so that they may open successively through varying strengths of suction against the variant tensions of the springs.

The Air Valves.—Several valves are made of leather, which is quieter in operation than metal. In some cases the tendency to chatter, or vibrate, is overcome by a diaphragm or dashpot. In recent models of the Pierce carburetor the auxiliary air inlet is controlled by flexible reeds of varying tension, which close air orifices and open progressively as suction increases. In other makes a series of openings are closed by balls of graduated weights, which lift from their seats with sufficiently strong suction.

The Throttle Valve.—The usual form of the throttle valve is that of a "butterfly" or damper, swinging on a centered pivot in the diameter of the tube. In many cases, however, a piston valve is used, which by sliding in the passage closes or opens the inlets to the cylinders, or varies their intake capacity. In some cases this piston valve rotates in the tube, turning a smaller or larger opening to the inlet ports, and thus regulating the amount of air and gas admitted to the engine. On the earlier types fuel regulation was effected solely by hand and required constant attention, with or without proper results, according to the judgment of the operator. The automatic air valve does away with the necessity of continuously manipulating the fuel and air supply, and when properly adjusted should give a correct mixture at all speeds.

Fixed Adjustments.—Carburetors with fixed adjustments are used on engines having valves controlled by a governor, while those with variable adjustment are used on engines which are controlled by the throttle. Those having variable adjustment are of two forms; viz.: those in which the volume of air is regulated in order to vary the explosive force

of the mixture, and those in which the relative proportions of air and gasolene are constant, the amount of the mixture which enters the cylinders being under the control of the operator so that a greater or less amount of fuel is exploded as desired. The latter is the prevailing type.

Variable Adjustments.—Adjustable carburetors of the spray type are capable of producing the correct mixture according to conditions and are of two varieties, viz.: (a) the positively controlled and (b) the automatic. In the first the control is effected either by hand or by a governor through suitable connections. Strictly, a throttling damper governs the volume of mixture without affecting its composition, but in many of this type, the volume of air alone is controlled, resulting in mixtures of varying composition. In the second variety, the air supply is also controlled, an auxiliary air inlet being automatically opened when the engine is speeded. In several more recent carburetors, principles of both these varieties are combined.

Automatic Carburetors.—In practically all carburetors of this type the auxiliary air supply is regulated by a spring-controlled valve, which opens due to the suction of the engine. When the speed of the engine is increased and greater suction ensues, the valve opens further and permits the ingress of a greater quantity of air.

Water-Jacketing the Carburetor. — The practice of jacketing the carburetor, or mixing chamber, in order to secure more perfect vaporization of the gasolene and more intimate mixture with air, and at the same time neutralize the tendency to freeze, which is experienced with high speeds, is adopted with many makes of instrument. The Longuemare was the first instrument to embody this feature, although it used the hot gases of the exhaust, rather than water from the jackets of the cylinders. Could the carburetor always be conveniently placed near the walls of the combustion chamber, as was the original Maybach, this jacketing would be unnecessary, but in presently followed designs, it is the only way to secure the desirable heating of the chamber. Heating the carburetor is also of material benefit in vaporizing the fuel, especially if it be alcohol, kerosene or low-grade gasolene.

General Thermal Conditions.—A carburetor if called upon to deliver a greater volume of mixture than its rated capacity, is subjected to a considerable loss of heat due to the forced evaporation. If it is cooled lower than the dew point, moisture will condense upon its surface, and in extreme cases may even appear as frost. Under such conditions, even high grade gasolene is no guarantee against poor results, and trouble is certain to ensue if low grade fuel is used. Any water which may have collected in the carburetor is also apt to freeze, prevent its proper action, and possibly cause a fracture. Under such conditions, to

heat the air supply is of some benefit. This may be effected by placing the opening of the air pipe in proximity to the exhaust or other hot place about the engine.

General Operative Conditions.—The three elements of (1) intimate mixture, (2) correct proportions of air and gas, and (3) automatic adjustment are basic, and must be kept in mind while considering the minor but important points of the perfect mixer. Most mixing devices heretofore constructed have aimed to provide for these three points, but more often than not each provision has been an imperfect one, and the results not of superior quality. The typical mixer of to-day takes air from the atmosphere at practically constant pressure, and liquid from a float chamber presumably having a constant level. Since, however, the volume of air required for a good mixture is at least fifteen hundred times greater than that of the liquid, and since the speed under a given suction is much greater than the speed of the liquid, it will be seen that wide opportunity for improper proportion exists. At very low speeds, the liquid may not be sprayed, but simply drawn from its nozzle in large drops, or even in a stream running down the outer walls of the nozzle. Also, at very high speeds the air inlet may be too small to admit a sufficient quantity of air for a good mixture. The difficulty of maintaining a proper proportion of air and gas under such wide variation may be readily understood.

Automatic Air Regulation.—To meet this difficulty the perfect mixer must automatically enlarge the supply of air, and vary the liquid to maintain it proportionate to the air, as the needs of the engine grow greater. To do this with certainty it should have a **diaphragm** acted upon by the suction of the engine, which diaphragm should be large enough to respond to slight variations, and thus prevent high vacuums, with consequent reduced power at high speeds. This method of providing for wide range is the only correct method. The mere opening of the usual auxiliary air port cannot perfectly perform this service, because the suction must increase considerably before the air port will open, and seldom or never is provision made for securing either intimate mixture or proper admission of proportionate volumes of air and liquid with this auxiliary device.

Compensative Operation.—Not only should this necessary automatic adjustment be operated by the suction of the engine, but it should be sensitive enough to prevent much variation in vacuum between high and low speeds. Also at high speeds the mixer should have openings large enough to admit the fullest possible charges, while at low speeds the opening should be small enough to secure sufficient air velocity to make a perfect mixture; that is, a fine spray of the liquid, properly proportioned and intimately mixed, even when turning the engine over by hand. This result can

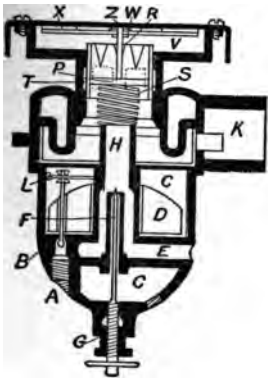


Fig. 25e.

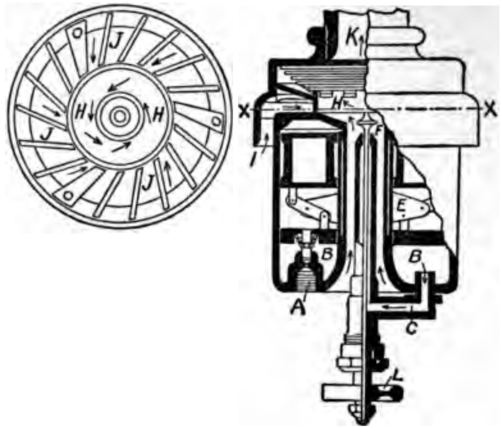


Fig. 25f.

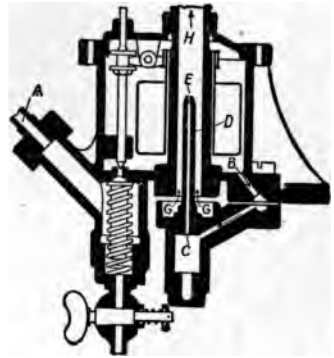


Fig. 25g.

Fig. 25e.—An early example of annular float carburetor, the Acorn Carburetor, showing details, for comparison with later types. A, gasolene inlet; B, inlet valve of ball type, to be opened by the rising of the float; C, annular float chamber; D, hollow metal annular float; E, air inlet port; F, spraying nozzle; G, adjustable needle valve on nozzle; H, mixing chamber; K, fuel inlet to cylinder space; L, hinge of the valve lever, which is lifted by the rising of the float; P, piston valve depressible by air suction, to admit air through the auxiliary air ports; S, spring holding piston, P, in normal position; T, annular channel around P, containing the ports for admitting air when the piston is depressed; R, rod on the upper face of P, which is attached to diaphragm, W, pulling diaphragm, W, downward with the piston, extending the pleated leather ring, X, admitting air through orifice, Z, and thus giving a dashpot action to retard movement of the diaphragm.

Fig. 25f.—Recent model of Watts Carburetor, showing details. A, gasolene inlet; B, float chamber; C, gasolene passage to nozzle, E, which is topped by adjustable valve, F; G, air inlet; H, mixing chamber; I, auxiliary air inlet; J, J, J, radial vanes through which auxiliary air is taken in; K, fuel outlet to the cylinder space; L, adjustment of needle valve.

(Caption continued at bottom of page 207.)

be attained only by permitting a large diaphragm to vary the size of the passage or passages under increased suction, proportionate to the increased speed.

Balanced Float Chamber.—The float chamber should be concentric with the liquid inlet, so that an inclination in any direction will not cause more or less liquid to be admitted. The float should be surrounded by a substantially concentric volume of liquid that will support and balance the float, with the result that sudden vertical movements, such as jolts, are without effect. This arrangement is superior to floats balanced by weights, in addition to the column of liquid, since the duties of the liquid and the weight may interfere and destroy the perfect balance sought for.

Construction of the Float.—The float should be a single piece, preferably without working joints, and, particularly, without frictional contacts with levers, which may sooner or later wear through its thin metal and cause it to leak. The float should be constant in weight and buoyancy, and is, therefore, preferably made of metal, since few cork floats can be depended upon to remain impervious to gasolene and retain their buoyancy. The float point should be adjustable, so that the level of the liquid may be maintained at the most advantageous point, in order, both to suit the vacuum necessary to make the proper spray, and also to overcome the effect of different heads of gasolene which may be used.

The Float Point Valve.—The float point may be of such taper and size as, in some degree, to vary the gasolene level in action, giving a higher level and better mixture at slow speeds. It should be easily ground so that it may be kept tight and in perfect working order. Further, the motion of the vehicle should tend to move the float point to some degree, even though slight, which movement serves to force away any particles of dirt that may lodge on the point during the passage of liquid. On this account, it is best, that the float and point should be fixed one to the other, so that the point may partake of the motion of the float in the chamber.

The Gasolene Inlet.—The gasolene should enter the float chamber from a single direction, either up or down, so that there may be no pockets in which water or dirt may gather. It is best to feed the chamber by gravity from a tank above the float chamber, and with downwardly extending pipe, without pockets, which leads into the chamber near the top, with upward extending float point attached direct to the float without levers, weights or other unnecessary parts.

Fig. 25g.—Recent model of the De Dion Carburetor, one of the earliest to have a concentric float chamber. A, gasolene inlet to float chamber; B, outlet to spray nozzle; C, entrance to spray nozzle, above gasolene pool; D, standpipe; E, orifice of nozzle; G, air inlet; H, fuel outlet to cylinder; I, gauze strainer around end of fuel inlet port to float chamber.

The Float Chamber Opening.—The float chamber should open at the bottom for automobile use. This arrangement facilitates removal of any water, ice or dirt, and removal of float itself, without opening the top and permitting dirt to fall in from above. The float and removable bottom can be replaced with a stream of gasolene flowing upon them, which will wash away particles of dirt, if any accidentally get on the parts while being replaced. With a top opening, ice in the bottom of the chamber may not only support the float and prevent its falling to admit gasolene, but may also bind the float so firmly that it cannot be removed to permit removal of ice, which may prove an unpleasant predicament, if away from means of warming the mixer.

The Air Vent and Primer.—The float chamber should have an air vent to permit proper action, and this vent should preferably terminate above the gasolene tank, so that if, for any reason, the float fails in its duty the gasolene rising in the vent tube will not rise higher than the tank level, and so cannot escape. Where convenient, the primer, or device for depressing the float and flooding the mixer, should pass down this vent tube. This arrangement, in connection with a needle that closes the nozzle, when the motor is stopped, prevents danger from leaking gasolene and possibly fire. It is more reliable than a stop cock, for the operator will grow careless about the stop cock, but will, if needed, adjust the nozzle daily to secure best results under prevailing weather conditions for that day.

Gauze Strainers and Screens.—All gasolene entering the mixer should be strained through ample gauze, so that particles likely to clog the nozzle may be kept from entering. Such gauzes are usually provided at the opening of the tank or in the funnel, but this is not sufficiently certain for the best results, and the perfect mixer should be self-protected from this certain cause of trouble.

Position of the Nozzle.—The outlet from the float chamber, usually termed the nozzle, should be nearly concentric with the chamber. If centrally located, variations in angle do not affect the level at this point, but it is some advantage to have this point slightly behind the center, so that going up hill or accelerating the action of the vehicle automatically raises the level of the liquid, and thus slightly increases the flow, making the mixture slightly more fat and powerful. This arrangement permits the normal mixture to be lean, insures perfect combustion, great economy, and no odor, yet automatically brings the mixture to maximum fatness and power, when power is needed.

Nozzle Proportions and Efficiency.—Since liquid has considerable weight, and consequent inertia, the passage to the nozzle should be both short and large, for large passages do not clog easily, and, if short, the liquid can flow quickly and will likewise cease flowing without delay when the suction

ceases. If large, the friction is less, and no particle of liquid need acquire high momentum. If, on the other hand, this passage is long, the liquid does not get started until a large volume of air has passed the nozzle, making the early part of the charge too lean, while as the suction decreases, and the air flow ceases, the inertia of the liquid causes it to continue to flow, making the latter portion of the charge overfat, and leaving between charges probably unsprayed drops of liquid, which fall upon the walls, or are drawn into the engine cylinders.

Liquid in the Mixing Chamber.—Such liquid as remains unsprayed in the passage should be retained, and not permitted to run into the engine or upon the ground. This liquid should also, by the shape of the passage, or by other suitable means provided, be broken up, sprayed or finely divided at the next suction stroke, so that it may properly serve its purpose within the engine. If, because of a faulty float, the nozzle should flood, the air passage should not fill with gasolene; for, when attempting to start the engine, this would result in a large volume of liquid being drawn into the cylinder, making its contents too fat to ignite. To prevent such flooding, the air passage should have an opening at a proper distance above the bottom, to permit the escape of excess liquid in case such exists.

Nozzle Adjusting Valve.—The nozzle should be closed from above by an adjustable needle, for the inverted conical point of such a needle assists in making a fine spray. This needle-adjusting handle should terminate near the operator and permit him, while operating the vehicle, to vary the proportion of the mixture, and thus secure the greatest power by trial, as well as accommodate the device to the temperature and humidity of different days, also to the gravity and composition of different fuels. No adjustment while the vehicle is standing can compare, in point of accuracy, with adjustments in actual road service. Further, the mixer should be adjustable at low speeds to secure certain ignition and steady running.

Provision for Constant Adjustment.—Gas engines are particularly liable to misfire at their limits and the perfect mixing device for automobiles will provide superior conditions at these limits, in order to secure the most satisfactory range of service. This necessitates provision also for adjustment at normal or high speeds, and by inference, the device should automatically compensate at intermediate speeds. Most present-day devices are adjustable for one speed only, and depend for automatic adjustment upon considerable variation in the suction vacuum. Consequently, they cannot give good results at speeds widely varied from that to which they are adjusted. This defect need not, and *certainly should* not, exist.

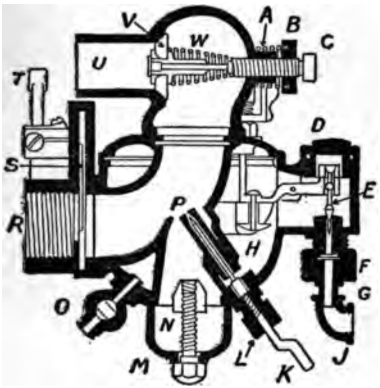


Fig. 25h.

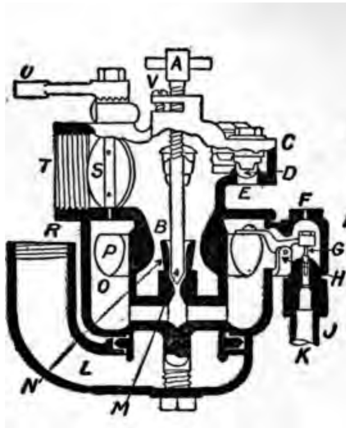


Fig. 25j.

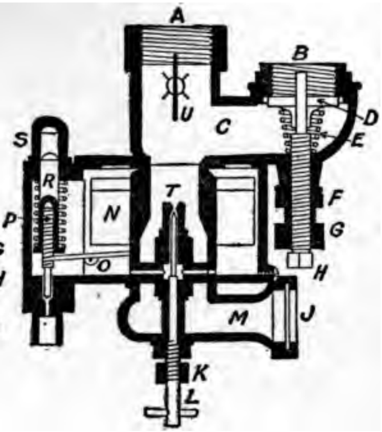


Fig. 25k.

Fig. 25h.—Recent model of Schebler Carburetor, showing details. A, lock spring on auxiliary air valve; B, lock nut on A; C, adjusting screw of auxiliary air valve; D, screw cap on float valve space; E, inlet valve controlled by float; F, union nut; G, nipple secured by nut; G, end of float attached to valve hinge; J, L-union for fuel feed; K, adjustable needle valve; L, packing nut on needle valve adjustment; M, air bend; N, primary air inlet; O, drain cock for float chamber; P, spraying nozzle; R, fuel outlet to cylinder; S, throttle disk; T, throttle lever; U, auxiliary air port; V, air valve disk; W, spring controlling air valve.

Fig. 25j.—Recent model of the Kingston Carburetor, showing details. A, gasolene adjusting screw; B, strangled section of mixing chamber, or "Venturi tube"; C, cage for ball valve; D, ball valve; E, auxiliary air ports; F, float valve cap; G, float valve; H, hinge of float valve; J, pipe connection to fuel inlet; K, fuel inlet; L, air bend; M, needle valve; N, spraying nozzle; O, float chamber; P, cork float; R, primary air inlet; S, throttle disk; T, fuel outlet to cylinder; U, throttle control lever; V, needle valve lock screw.

(Caption continued at bottom of page 211.)

Design of the Air Inlet.—That the largest possible charges may be drawn into the engine at high speeds, it is self-evident no needless friction should be encountered by the air as it passes toward the engine. On this account, a single air passage is better than several, because there is less wall surface and friction. It is also evident that the air passage should be easy and not tortuous or broken. It is undoubtedly true that the tortuous passage will break up the particles of gasolene and help to form a homogeneous mixture, but this is done at the cost of increased suction and of some loss of volume and consequent needless loss of power from the motor, particularly at high speed.

Provision Against Back-Firing.—Since most engines may occasionally back-fire through their inlet valves, the mixer should be provided with escape for such explosion. If this is not done the pressure may force into the float chamber, and will more certainly interfere with the next succeeding charges, than if allowed to escape into the atmosphere freely and promptly. To prevent such explosions from igniting anything on the outside, the pipe entrance should be provided with a gauze strainer. This serves to keep out particles of dirt that, otherwise, would enter the engine, stick to the walls and cause rapid wear and pre-ignition. Much of the "carbon deposit," so common in automobile engines, is caused by road dust with enough oil to bind it together in a solid mass.

Heating the Mixing Chamber.—The rapid evaporation of the liquid not only takes heat from the passages in which the evaporation takes place, but frequently causes a deposit of moisture, which, in the presence of low atmospheric temperature, becomes ice and clogs the passage. This freezing may be prevented and a more perfect evaporation, with consequent intimate mixture, secured by heating the passage where the mixture is taking place. It is desirable, therefore, to have a heater jacket outside the mixture passage, through which hot gas from the exhaust or hot water from the circulating system may flow. It is also advisable to place within the mixture passage at this point one or more gauzes of large area to intercept large particles of liquid and prevent their being carried into the cylinder. All gauzes should be removable for cleaning purposes, and frequent attention to the various details of this most essential part of the vehicle is necessary to insure perfect work.

Fig. 25k.—Recent model of the Holley Carburetor, showing details. A, fuel outlet to cylinder; B, auxiliary air port; C, mixing chamber; D, air valve on auxiliary air port; E, spring controlling auxiliary air valve; F, lock nut on screw controlling movement of the auxiliary air valve; G, adjusting screw controlling movement of the auxiliary air valve by varying the tension of the spring, E; H, adjusting screw controlling movement of the auxiliary air valve; J, primary air inlet with gauze screen; K, needle valve packing nut; L, handle for adjusting the opening of the needle valve on the spraying nozzle, T; M, air bend; N, hollow metal float; O, inlet valve hinge of lever bearing on bottom of float; P, fuel inlet valve; S, float valve cap; T, spraying nozzle; U, *butterfly valve disk.*

Usual Carburetor Operation.—The typical present-day carburetor has a float chamber usually at one side of the air passage, and a long, small nozzle for gasolene reaching into the air passage, which at this point is strangled, or contracted, to increase the velocity of the air past the nozzle. Between the nozzle and the engine an auxiliary opening is provided, closed by a spring valve, which, when the suction is increased sufficiently, opens more or less, admitting a quantity of pure air with which to dilute the over-rich mixture coming from the strangled passage. The action of this device is about as follows: At extremely slow engine speeds, say under 200, the mixture is imperfect, because the air passage is not small enough to give proper air velocity for a suitable spray. This is one of the reasons why the gas engine is regarded as inflexible, and why many engines fail to develop power as soon as their speeds are reduced. If this passage is small enough for perfect running at very slow engine speeds, say 50 and 100 with throttle practically closed, it is too small to admit a practical amount of air at higher speeds, so the gasolene by itself, or badly mixed with air, is drawn from this passage, while the greater portion of air, with imperfect provision for mixing, enters at the auxiliary valve. Clearly, this arrangement cannot be depended upon to give a proper mixture or proper proportion. Next, it must be remembered that, while the strangled passage is constantly open, the auxiliary passage is closed, except when sucked open. Further, the auxiliary valve flutters, and the result may often be that, in the early part of a stroke, the mixture is exceedingly rich, because it all comes from the strangled passage, while later, the auxiliary having been sucked open, a large quantity of air enters (larger than necessary), with resultant poor mixture, followed by closing of the valve, as the suction decreases near the end of the stroke, with consequent rich mixture at this time. In addition to this, the gasolene will continue to flow in a long, slim nozzle for some time after the suction stops, because of its momentum; thus, as will be seen, the beginning and end of each charge are probably overfat, while the center of the charge is very lean.

Ideal Carburetor Operation.—There is also a wide range of suction variation, because at the beginning and end of the stroke there is little or no vacuum, and the strangled tube offers a free passage, while at the center of the stroke there must be, and is, enough vacuum to open the auxiliary, so it is quite evident that the engine is not drawing uniformly, and is not free from that negative pressure, or vacuum, necessary to get the largest charges, and to avoid needless loss of power. The ideal carburetor will avoid this irregularity by opening a passage proportionate to the amount of mixture required, and it will not only open the air passage, but it will adjust the gasolene to suit. If, for example, there is provided a piston or diaphragm, operated by the suction of the engine in one direction and by gravity in the other,

with a dash pot so that it cannot flutter, it may be made to open the air passage and to adjust the gasolene, so that, with little or no increase of suction, the proper amount of air and liquid is admitted. With such arrangement the vacuum need only be sufficient to give the air the necessary velocity required to make a proper spray, and higher speeds

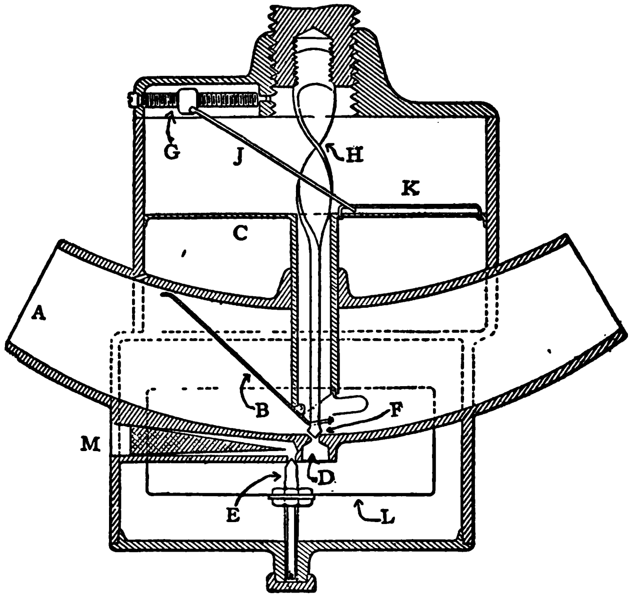


Fig. 251.—Sectional diagram of the Duryea Mixer, showing details of construction. A, air inlet; B, air gate, hinged to the foot of the diaphragm stem, so as to raise it with an extra draught of air, thus enlarging the air inlet in proportion; C, the diaphragm which rises under the pressure of the extra air draught, as explained, causing radius bar, J, to slide on slot, K, and bearing against the twisted flat portion, H, of gasolene adjusting needle, F, causes it to turn upon the internally threaded plug in which it is hung, thus opening the gasolene supply to the mixing chamber, from passage, D. The screw, G, adjusts the position of radius bar, J, in slot, K, thus, also, the amount of rise of the needle valve, F, as explained. The float, L, is in two semi-cylindrical sections, between which is a common cross-piece carrying inlet valve, E, closing the port from the gasolene inlet, M, which contains a conical gauze strainer, as shown. The gasolene admitted to the mixing chamber forms a small puddle at the bottom of the bend, the amount admitted being determined by the draught of air, which raises the air-gate, B, and the needle, F; thus keeping the mixture at a constant quality.

will not starve the engine because of higher vacuum. The dash pot insures average openings, so that at the beginning and end of the stroke the velocity will be low, at the middle high, but with an average somewhat higher than the least practical velocity, while good results may be obtained, even *during the slow* portions of the stroke.

Design and Temperature Conditions.—Many typical carburetors have passages with quite abrupt corners. This decreases the amount of air that can enter and thus impairs the efficiency. Some provide for complete vaporization within the carburetor, or very close thereto, with the result that in wet weather the moisture of the atmosphere is condensed, and in cold weather frozen, thus choking the device with ice. It is better practice to carry the spray some distance, and thus distribute this refrigerating effect with less likelihood of ice formation.

Defects of the Single Adjustment.—The typical carburetor has but a single adjustment for the gasolene. It is argued that the gasolene may be adjusted for low speeds when the auxiliary air valve is shut, but this very frequently does not give the proper quantity of gasolene for high speeds, so it usually becomes necessary to adjust by guess, and after a trial adjust again, until an adjustment is found which gives fairly good results at high speeds, and permits operation and power effect at low speeds. That this is not ideal is readily seen. The ideal method would vary the air passage so as to supply the requisite amount of air with the least possible variation in vacuum and would also vary the amount of gasolene to suit this amount of air.

The Need of Double Adjustments.—The ideal mixer should be adjustable at low speeds for starting or running the engine idle, and it should also be adjustable at maximum or normal speeds, so that the best possible condition can be had at this time. It should automatically vary this normal or running gasolene adjustment as the proportion of air is varied. In short, it should have no less than four adjustments, two of which (*i.e.*, gasolene and air) are automatic, and two of which are manually operated, as indicated by the behavior of the motor. The typical mixer has but half this number, and these badly arranged.

Requirements of the Perfect Mixer.—In conclusion, the requirements of the perfect mixer may be summed up as follows: It must intimately mix, properly proportion and satisfactorily adjust, and also have the following specifications: (1) Float chamber concentric with inlet and nearly concentric with outlet; (2) Float of metal with point adjustable by the operator while driving (it should have adweights of float; (3) Float point easily ground, and moved by any motion of the float (the float should be free from balance-weights or levers); (4) The mixer should be adjustable by the operator while driving (it should have adjustments for very low speeds and also for normal or high speeds, and should automatically adjust between these speeds. It should have a short gasolene passage for quick action and a large gasolene passage to prevent clogging or *ramming.* It should retain in the air passage unsprayed *liquid, but* have provision to let out any excess); (5) A

gauze strainer at the gasolene inlet, and also at the air inlet, allowing the gasolene to flow in a single direction, either up or down, to the float chamber from the tank; (6) A vent at the top of the float chamber, which should, if possible, open higher than the tank (it should have removable bottom and a means for daily use to shut off the gasolene); (7) The air passage should be easy and single, rather than multiple, and have a removable gauze to prevent unsprayed liquid reaching the engine (this passage should be adjustable to the engine speed by the amount of suction, and should open freely in a reverse direction to permit back explosion to escape); (8) A dash pot must prevent fluttering with change of opening, so that the suction vacuum is closely constant; (9) Provision for heating is necessary in cold weather or with low gravity liquids. A mixing device which meets these requirements leaves little room for improvement.

CHAPTER XXVI.

Ignition Methods and Devices.

Conditions of Ignition.—In order that power may be produced by a gas engine, it must be substantially right in three distinct lines, viz.: mechanical, chemical, and electrical, if electrical ignition is used. The mechanical parts can usually be inspected, or their condition ascertained, by turning the engine over, and feeling, as well as seeing, the behavior of the parts. If the chemical part, the explosive mixture, is not suitable, it can be tested by removing a spark plug, or, in some such manner, gaining access to the firing chamber, after which the quality of the mixture may be ascertained with sufficient accuracy by applying a torch or taper, and noting the color of the resultant flame. If the mixture is too lean, it will barely burn in the presence of the flame and will be blue in color. If too fat, that is to say, containing an excess of fuel, it burns yellow with more or less smoke. The condition of the electrical apparatus is not so easily ascertained, because the presence of the electric current cannot be seen, and often cannot be felt, but must be found by noting sparks where the circuit is broken, or by delicate instruments not commonly used. Because of this delicacy and obscurity, the electric ignition of the gas engine is considered the most troublesome part of the whole system and one which most deserves suspicion when trouble occurs.

Methods of Electrical Ignition.—Two kinds of electrical ignition are in common use, and, while they are called by different names, they may properly be termed the primary and secondary systems, more commonly, however, "make-and-break" or "jump" systems. The primary system is complete in itself as a single electric circuit, but the secondary system uses a second electric circuit, in addition to the primary. The primary system is, therefore, the simpler of the two, but more commonly users believe the secondary system to be less complicated. The reason for this is that the primary system uses more recognizable and prominent

mechanical parts, with very slight electrical complication, whereas the other system has greater electrical complication with apparently fewer mechanical parts.

Conditions of Electric Sparking.—Having grasped the thought that an electric current flows in a circuit from one pole of its source of production back to the opposite pole we are now prepared to consider its use in gas-engine ignition. If this circuit between the poles of a battery or mechanical generator is broken a spark may usually be seen at the break. This, spark, however, is quite faint unless enlarged by means hereafter described. Electric current flows, as a rule, only through those substances termed conductors, that is to say, through most of the metals, and some other substances, but in our description we need consider it only as flowing through wires, usually of copper. If this wire is broken, the gap contains air, of course, and air is a good electrical insulator; rapidly increasing in its resistance to the passage of the current, if compressed. That is to say, the electric current flows easily through an almost complete vacuum, but with much more difficulty through air spaces at atmospheric pressure, and with very great difficulty through compressed air. This latter fact explains why a "jump" spark, as described later, will jump a half-inch or more in the open air outside of the engine, better than the $\frac{1}{32}$-inch gap between the spark points inside the engine at the time of compression.

Use of the Spark Coil.—To increase the ability of the spark to jump the gap at the break a coil is used. The primary coil consists of a core of soft iron, usually a bundle of straight wires, from five to ten inches long and generally ¾-inch, or thereabouts, in diameter, around which is wound from four to ten layers of Nos. 16, 18, or 20 insulated copper magnet wire. Passing the electric current through these wire layers saturates the core of iron wire, making it magnetic. In thus saturating the core the energy of the electric current has exerted its greatest influence, and if it is interrupted by breaking the wire, when the core has become fairly well saturated, a large spark appears at the break, and will jump a considerable gap between the ends of the wires. In effect, this spark is much the same, as if a small stream of water, interrupted by a dam, until a considerable quantity of water had gathered in one spot, and then the breaking of the dam had released in one instant a large amount of the water. Such an effect produced in the spark coil involves that its circuit must be connected for an appreciable time so that the core may be "charged," as the magnetic saturation of its core is termed, and then, when the circuit is broken, the discharge of the core results in the large spark. This large spark is due to the effect of the discharging magnetism of the core on the coils of wire surrounding it.

Conditions for Producing the Primary Spark.—In gas engine *practice the* primary spark is produced in the engine

for ignition purposes by carrying at least one insulated terminal or electrode, through the cylinder wall, and making a connection, so as to complete the circuit within the cylinder, with means whereby it can be broken at this internal connecting point at the proper period in the engine's action. The means of breaking within the engine are not important to this description, the point being that there is a battery or other source of electricity, a coil in which some electrical and magnetic energy may be stored, and a means of breaking the electric circuit within the engine at the proper time. Since the effect of this coil is to greatly increase the e. m. f. at the break in the circuit it is evident that an electric source of much higher e. m. f. would produce a large spark with a much smaller coil, but since it is not convenient with modern commercial batteries to carry a high voltage, we need not here consider the apparatus necessary to produce a workable spark without the use of a coil.

Piston-Operated Make-and-Break.—In its simplest form, the connection inside the engine may be arranged so as to be operated by the piston on its upward stroke. Thus the wires forming the electric current may terminate in two insulated electrodes, of which the inner ends are elastic, one being placed slightly lower than the other and both so arranged with respect to the piston that, as it nears the upper end of its stroke, it presses one electrode against the other, completing the circuit and charging the coil. As the piston starts to descend, it permits these elastic electrode ends to separate, making the spark, which ignites the working charge and drives the piston downward. This form, while used to some extent in stationary engine practice, is not durable nor commendable.

Defects of the Piston Make-and-Break.—To secure good ignition the gas must be heated by the electric spark and a spark produced between the two metal pieces cannot expend its heat in igniting gas because the presence of the metal chills both the gas and the spark and is likely to cause failure to ignite. On this account it is common to use some form of apparatus for breaking a circuit normally made, and which operates quickly, to the end that the spark may be both larger and more effective. If the electric circuit is broken slowly the current dies gradually, and at the completion of the break a very small and weak spark is obtained. If, however, the current is interrupted suddenly by a very sharp, quick break at the points, the entire e. m. f. is expended across the gap, with resultant large spark and much heat.

The Hammer-Blow Breaking Apparatus.—The Hammer-blow breaking apparatus is, therefore, the common kind. It may be understood by considering one electrode as pivoted to the inner wall of the engine, with its free end in contact with the other electrode, insulated from the metal of the cylinder, thus completing the circuit. One form of this

device has a pin or projection on the piston which strikes the pivoted electrode near the pivot, as the piston nears the upper end of its stroke, thus throwing the free end out of contact with the insulated electrode, and producing a large spark. Such form of device was used on the early Duryea

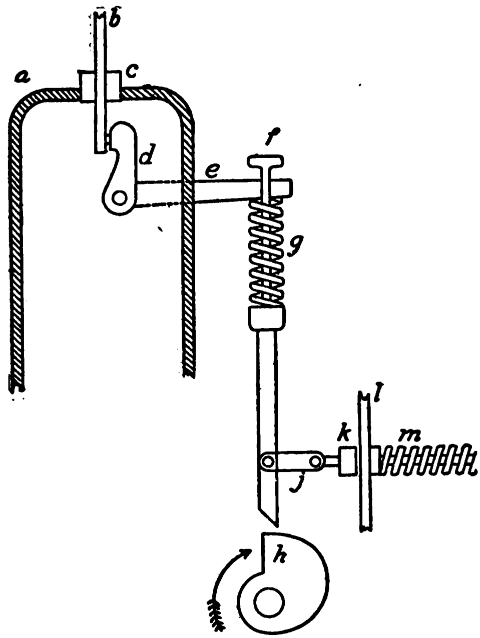


Fig. 26a.—Diagram of a typical primary ignition device of the "hammer" form, showing the essential elements. At *a* is the cylinder wall; *b*, the fixed electrode carrying one side of the circuit; *c*, the inserting nut for the holding and insulation of *b*; *d*, the swinging hammer contact for making the spark when drawn away from contact with the end of *b*; *e*, the swinging arm carrying *d* and pivoted on a rod extending through the cylinder wall from the outside; *f*, pushrod holding the contact spring *g*, against the arm, *e*, until its lower end falls into the notch on cam, *h*, allowing its head to fall pulling *e* away, so that the contact between *d* and *c* is broken and the spark produced; *j*, link and slide rod held in position shown by spring, *m*; *l*, timing lever. By adjusting the position of the nut, *k*, or moving the lever, *l*, the end of rod, *f*, falls into the notch of the cam earlier or later as desired, thus advancing or retarding the spark.

vehicles nearly twenty years ago, and formed the first successful example of electrical ignition on automobiles. Later forms, however, did not depend upon the piston for operation. although the movable, or pivoted, electrode was still used for many years, but the stem or pivot of this part extended through the cylinder wall, and was operated by a sort of hammer on the outside, which, striking a blow, knocked the

contact points apart still more abruptly than was possible by the slow motion of the piston at the end of its stroke.

The Primary Spark from Magneto Current.—When a mechanical generator is employed instead of a battery, this is usually a magneto, although small dynamos have been much used. The magneto consists of an armature revolving between the poles of permanent magnets and this revolving armature delivers a current of electricity. The e. m. f. of this current depends upon the speed of revolution while the amperage depends upon the size of the wire used and the size of the parts. A very common magneto for make-and-break spark is about 10 volts and 3 amperes, which is passed through a spark coil somewhat smaller and wound with finer wire than the usual battery coil, although the same coil is often used.

Driving the Magneto Generator.—The magneto is driven by belt or friction or other suitable means and simply takes the place of a battery. If a larger current is wanted, a small dynamo is used, which differs from the magneto in that an electro-magnet or field piece is used instead of the permanent horseshoe magnets proper to the magneto. If, however, it is convenient to gear the magneto, so that it turns in step, or at the same speed, as the engine, the magneto may be constructed somewhat differently. Its armature, instead of being of the multi-pole type and fitted with brushes for taking off the current from each pair of poles successively, may be of two-pole type, one pole being grounded on the axis of the armature, while the current from the other is taken off by a single brush. This form of magneto is commonly termed an alternator, because the electric impulses are alternately in opposite direction and not continuously in one direction, as is the current from a battery or multi-pole generator.

Construction of the Alternating Magneto.—Usually the alternator has its armature wound with sufficient wire to serve as a spark coil, so that no coil is needed, but breaking the circuit at the peak, or strongest portion of the electric impulse, produces a spark of the intensity and heat desired, and serves its purpose perfectly. Some designers have built the alternating magneto into the engine in such a way that it produces an impulse when a spark is needed, and thus they secure a most reliable generator having no wearing of parts other than the engine parts, needing no coil, and having no wires, except a single lead from the magneto to the spark plug. If the engine is a two-cylinder one, both ends of the armature wire must be brought out and one taken to each plug. If the engine is a four-cylinder, multi-poles must be used with a wire leading to each plug, or some similar arrangement provided.

Advantages of Primary Spark Apparatus.—The extreme *simplicity* of the mechanical part of the make-and-break

ignition apparatus commends it to the use of the general public, who are presumably not electrical experts, but who can see and understand the functions of its several mechanical parts. Further, these mechanical parts need not be complicated, but can be made quite simple, and thus easily understood, as well as quite durable, so that little attention is required by them. In the rapid development of the gas engine, as applied to the automobile, the perfecting of the parts of the make-and-break system did not keep pace with the increased speeds of the engines, not because these parts could not be made sufficiently quick-acting, but simply because makers did not recognize the limitations of the heavy, slow moving parts, and it became more or less generally assumed that the make-and-break mechanism was not adapted for high-speed engines. This assumption, however, is wholly unwarranted. The moving parts necessary in this system can be made just as small, also as delicate and as rapid as the moving parts of the secondary or jump-spark system, if there is occasion to make them so, and it seems quite likely that, at some near future date, there will

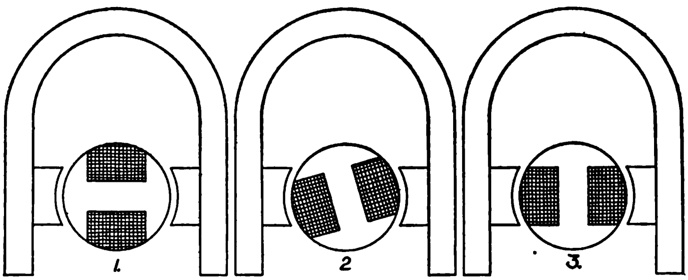


Fig. 26b.—Diagram of the operation of the common type of magneto-generator. At 1 is shown the position of the armature in which the flanges being opposite the pole pieces, the greatest magnetic activity takes place. At 2 the magnetic activity through the metal of the core is decreasing. At 3 the magnetic circulation passes through the wire layers of the winding, giving the minimum effect.

be a reversion to the original type and that the make-and-break spark will again enjoy the leadership that it formerly had. The generally-admitted fact that an automobile engine requires two ignition systems indicates the unreliability of present-day methods, and emphasizes the fact that gas engines for years have been used with but a single system, when this was of the primary type.

Objections to Primary Spark Ignition.—Another objection to the make-and-break mechanism was the difficulty of holding the points in contact only sufficient time to charge the coil. A shorter time would not produce a proper spark and a longer time wasted battery; batteries being generally used *with this system.* Where the engine operated at a

fairly constant speed, as stationary engines do, this time of contact could be adjusted, and good battery economy with a large spark secured, but in an engine capable of running from 200 to 2,000 turns per minute, or even at a wider range, the length of contact was not so easily varied. If it was made to cover a certain portion of the crank movement, then the time element would be either too short for the high speeds or too long for the low speeds, and if we assume that the contact was long enough to properly charge the coil at 2,000 r. p. m. then it would be ten times longer than necessary, with consequent waste of current at the slow speeds, of 200 r. p. m.

Recent Improvements in Current Generation.—A number of devices have been employed to insure a constant length of spark point contact in the primary system, much as is well known in the jump system, and something of this type is a necessity, if batteries are to be used in connection with engines of widely varying speeds. Since, however, magnetos are so simple and so cheap to build, and since electric lighting has become an accepted fitting on modern automobiles, it seems certain that the battery matter will be less considered by future builders and that, having ample current at command, they will not question the length of contact on the ignition system as in the past. With the alternating magneto the peaks of the electric impulses can be timed to occur when the break is desired, so that the electric impulse is ready to make a splendid spark, when the circuit is broken, and the length of contact prior to this peak largely occurs during the neutral, or non-productive, period of the magneto, with no especial loss of current or power.

Break-Spark Contacts.—In the make-and-break ignition it is necessary that the spark points come together with some pressure, so as to insure a good contact and an easy flow of current to fully charge the coil and that they remain in contact long enough to allow the coil to become charged. An instantaneous contact and break is not sufficient, with the usual source of electricity and the usual coil. When the circuit is broken by the sudden hammer-blow separation of the contact points, it is advisable that they separate more than an eighth of an inch or approximately a distance equal to their diameters. In order that these points may be of long life, it is quite common to make them of about one-eighth inch size or diameter and of some metal which does not corrode easily. The very best points are of an alloy of platinum and iridium, which is very hard and not easily machined. Pellets of this material, formed by fusion, are used in best-quality apparatus, and are brazed to the metal parts forming the make-and-break mechanism. Some makers, however, use a less expensive metal such as silver or an alloy of silver and nickel, copper and nickel, pure nickel or some similar material, which is hard enough to stand the constant contacting of the points,

and resistant enough not to burn away rapidly. Quite recently tungsten points have come into use.

Conditions of Spark Failure.—If the metal oxidizes, or burns easily a hard, non-conducting scale is likely to be formed, which is not easily removed and causes mis-fires. It is well known that a low-voltage, high-amperage current disturbs the metal forming the points much more than a current of lower amperage and higher voltage. On this account the old type of battery burned the points much more than does the modern magneto.

Quickness of the Break Spark.—One great advantage of the primary ignition system is the smaller time loss after the break occurs. If the breaking mechanism is operated by the piston of the engine, the spark follows the break with no lag whatever, so that if produced at the proper point in the crank movement, at one speed, it will not need much variation for other speeds. This is radically different from the conditions existing in the jump-spark system, in which the break is usually produced by a vibrating blade or spring, or by a moving mechanical part released by the engine.

Comparison with the Jump-Spark Coil.—If the vibrator coil is used, the engine closes the terminals of the primary circuit when the spark is supposed to be produced, but, after this closing of the circuit, the coil must be charged sufficiently to attract the vibrator, which must be drawn away from its contact point, breaking the contact, and causing the spark by a discharge across the separated terminals of the secondary winding. The time required after the original closing of the circuit, until the vibrator breaks the circuit, is a matter largely depending on the vibrator speed, and of the ability of the coil to charge and discharge quickly. This time can usually be lessened, if the vibrator action is strong, by adjusting the vibrator points until the vibrator buzzes with a high-pitched sound, but, even then, there is a considerable loss of time. On this account the spark mechanism must be advanced, so that, when high speeds are employed the original closing of the circuit comes much earlier with relation to the crank shaft movement. In the make-and-break system, the circuit is either normally closed, or is permitted to close at some early point, so that the coil is charged and ready to discharge, when the break is made. Then, if the mechanism is positive, the spark occurs at the break immediately, with little or no lag or necessity for a spark advance.

Spark Advance in the Primary System.—While, as already stated, the amount of spark lever advance needed in any instance depends largely on the variety of mechanism employed to make-and-break the electric circuit, it is a fact that a smaller advance is necessary in the case of the primary spark, because there is no secondary circuit, with some lag

between its action and the action of the primary circuit, and because the original primary circuit is broken inside the cylinder, so that ignition instantly follows the break. Further, the primary circuit produces a larger and hotter spark, and, on this account, produces combustion more quickly. All of these causes contribute to requiring a smaller advance of the spark lever. The ordinary jump-spark coil is quite rapid in action, so that the amount of time lost between the breaking of the primary circuit and the production of the spark is not large, but it is a measurable period, and at high speeds its effect must be reckoned with. It is easy to make contacts too short to properly charge such a coil, and this is evidence that discharging it requires an appreciable period of time.

Sizes of Sparks Compared.—Not only is the make-and-break spark quicker, but its effect after being produced is quicker. The jump-spark is exceedingly small. This can readily be proven by passing a thin sheet of paper between the spark-plug points and noting the minute holes burned in the paper by the passage of the spark. If the paper is moved while between the points, the successive sparks produced by a vibrating coil will perforate a line of holes across the paper sheet. A sharp eye is required to see these holes at all, and usually it is necessary to hold the paper to the light, in order to make them visible. Their diameter varies according to the adjustment of the coil, the thickness and quality of the paper, the battery used and other causes, but probably does not exceed .001 of an inch. It is not easy to get a parallel comparison of the make-and-break spark diameter, because the make-and-break spark will not pass through a sheet of paper unless a metallic contact has been first established. This can be done with reasonable success as follows: Connect one terminal of the circuit to a metal plate and the other to a common brass pin; hold a sheet of paper 1/32 of an inch above the plate, and make connection by sticking the pin through the paper sheet against the metal plate, and then break the circuit by a quick jerk; better yet, by some form of hammer blow, which will withdraw the pin from contact, and out of the paper. The large, hot primary spark will follow, burning a hole through the paper, often 1/8 inch or more in diameter. The comparative heat of the two sparks is thus well shown. The make-and-break spark, having burned a hole an eighth of an inch in diameter, clearly requires and possesses many times the heat of the jump-spark.

Importance of Spark Size.—The size of the spark has an important bearing. The jump-spark being an extremely fine point, it is evident that the flame must spread from this exceedingly minute point in every direction until the whole charge is ignited. At the beginning of any ignition the heat expends itself, warming the gas to the ignition point, and there is no heat to spare, so that ignition at first is quite slow. This may be noted in any kitchen fire, in which the

first few minutes produce little effect but in which the fire burns rapidly after getting started; or in a burning building, where the damage done in the first few minutes is quite small, while the fire often becomes uncontrollable after getting a good start. So also, in gas engine ignition, the time required for a flame to spread from the minute point of the jump spark out to the circumference of a sphere, represented by the make-and-break spark, may be a large proportion of the total time required to complete the ignition. This seems to be one important reason why the jump-spark requires further advance than does the make-and-break.

Importance of a Hot Spark.—The low-tension spark has another very decided advantage. Being hotter and larger, it is more certain to come in contact with inflammable material in engine charge, and more certain to ignite it than the smaller jump-spark. It is well known that no carburetor gives perfect mixture, and that the quality of the mixture differs at different speeds, and under different weather conditions, and with different fuels. It is also well known that high economy results from the use of lean mixtures, but that lean mixtures require more heat to start combustion, so, on these accounts, the large make-and-break spark is to be commended. Experiments have shown that engine power is perceptibly increased, the fuel adjustment and throttle remaining unchanged, if two sparks are employed instead of one, the two sparks being simply a means of doubling the heat possibly generated with one jump-spark. The make-and-break spark, having many times the heat of the jump-spark, undoubtedly gives more power to the engine than is possible with even two sparks of the jump variety.

Small Advance of Low-Tension Spark.—Because of the quick action and the large heat and igniting ability of the low-tension spark, not only is a smaller advance of the spark lever required, but, in some engines, no advance at all is used; some makers believing that their engines deliver more power, if the spark is slightly retarded, that is to say, if it occurs after dead-center, instead of at or before it. This claim is possibly true with slow-speed engines of moderate size, but in large engines, which require more time to spread the flame throughout the charge, and in engines of such speeds as are used in automobile practice, the need for some spark advance is obvious.

Mechanical Spark Adjustment.—In a multiple-cylinder engine employing the make-and-break system there is sometimes some difficulty in adjusting the sparks, so that they all occur at the same point with relation to the piston movement, or to the crank-shaft position. This difficulty, however, is a matter of mechanical design, rather than to anything inherent in the system. The same difficulty is found in connection with the multiple jump-spark coil. If vibrators are used to produce the sparks, it is practically impossible to tune

them all alike, or, if so adjusted, it is scarcely possible that they respond with perfect uniformity. Thus, if the vibrator begins its second movement before the vibrations of the first electric impulse have ceased, there is no way of causing the second spark to take place at the same point of the piston stroke as the first one. Clearly, the vibrator cannot be affected by the magnetism of the coil core until it has completed the circuit, and maintained it completed long enough to properly charge the coil. But if, while still vibrating, it is drawn out of contact, the coil may not be fully charged, because the vibrator is moved, not alone by the attraction of the coil core, but partly by the vibration effect of the preceding movement, with the result that the time is shortened, and the spark weakened, while, on the other hand, the opposite may occur; the preceding vibration lengthening the time of contact, with a consequent more complete charging of the coil and larger spark, which would partly overcome the loss of time.

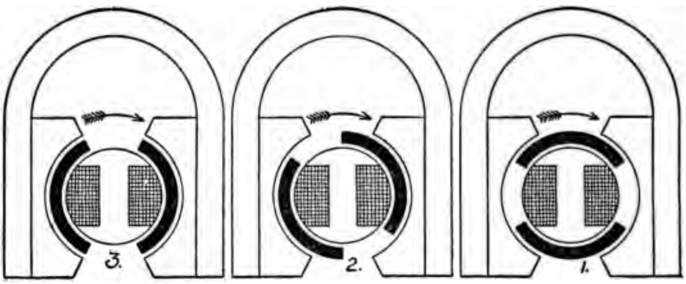


Fig. 26c.—The Simms-Bosch low-tension magneto, showing the positions in the rotation of the open sleeve around the stationary shuttle armature, from lowest to highest magnetic activity. At 3 the open sleeve is opposite the pole pieces, so that the magnetic circulation is all through the wire of the windings. At 2 the rotation has brought the sleeve to an intermediate position, in which the magnetic activity is increasing. At 1, the sleeve sections being opposite to the flanges of the shuttle armature, the greatest magnetic activity is taking place, through the metal of the armature, and thence through the windings or the coil.

Accurate Timing of the Contacts.—Not only must the vibrators of the several coils of a multiple-cylinder engine be accurately adjusted, but other disturbing causes enter. The contacts which complete the circuit, and operate these coils, must be exactly equidistant so that they close the circuit and start the vibrators at precisely the same point, with relation to the piston movement. This is a matter of more importance than most people imagine, and many timers are not accurate in this respect, or, if accurate when made, have lost their accuracy by wear, or by the burning and pitting of the conducting parts. Ignition apparatus makers have attempted to overcome the troublesome impossibilities

of similar adjustments, required in the use of multiple-coils with multiple point-timers, by substituting a single timer, single coil and a spark distributor or a master-vibrator for the multiple-coil. These devices are of importance, and should be commended, although not complete remedies for these defects.

Stationary Armature Magneto.—The simplest primary system, and one that is destined to be more used in future, is now found in farm engines and similar motors, and, occasionally, in automobile practice. It consists of a built-in magneto, forming a part of the engine, usually being placed in the fly-wheel. Being built in, it moves with the engine, and is, therefore, constantly in step. It has no gears, chains nor bearings. The field generally revolves, leaving the armature stationary, and this armature may be fixed or movable to permit advancing, if required. A modification of this type is used on Ford cars for both ignition and lighting, the current from the stationary magnets being carried direct without brushes or intermediate means to the coil, where it is transformed into high-tension current and used in jump-spark plugs. A much simpler arrangement is to carry the current from the coils direct to make-and-break plugs without the use of a coil. Such a connection is of the greatest simplicity and greatest reliability. The make-and-break plug may be piston-operated and just as easily exchanged, if defective, as is a jump-spark plug, while, having no high-tension wiring, the insulation may be of the simplest and most positive kind, free from danger of breaking and practically proof against short-circuiting.

The Jump-Spark System.—The jump-spark system is possible because of two simple facts. If an electric current passes through a wire, the wire becomes magnetized, and if a closed circuit of wire is exposed to magnetism, a current will be generated by induction in the wire. The original circuit between the terminals of the battery or other source is called the primary circuit, while the circuit containing the current induced by the magnetism is called the secondary circuit. This magnetic result of a current flowing through a wire can readily be demonstrated by anyone having a single dry cell or any source of current and a pocket compass. If the wire with the current flowing through it is held over the compass needle, the needle will swing crosswise the wire and the north pole of the needle will swing toward the thumb of one's right hand held over the wire with the fingers pointing in the direction the current is flowing, that is toward the negative pole of the battery. If the wire is held under the compass instead of over, the needle will turn in the opposite direction, or to make the needle turn in the same direction the current must flow through the wire under the compass in the opposite direction. This fact is taken advantage of in the construction of a simple galvonometer, which is made by passing the wire around the compass

as many times as may be desired, as over and then under, each passage or coil adding its effect on the needle to the other coils, so that the instrument becomes very sensitive and the needle will swing crosswise upon the passage of a very minute current of electricity, while the strength of the current can be somewhat gauged by the amount of sway of the needle. The common testing meter is built in a much similar manner.

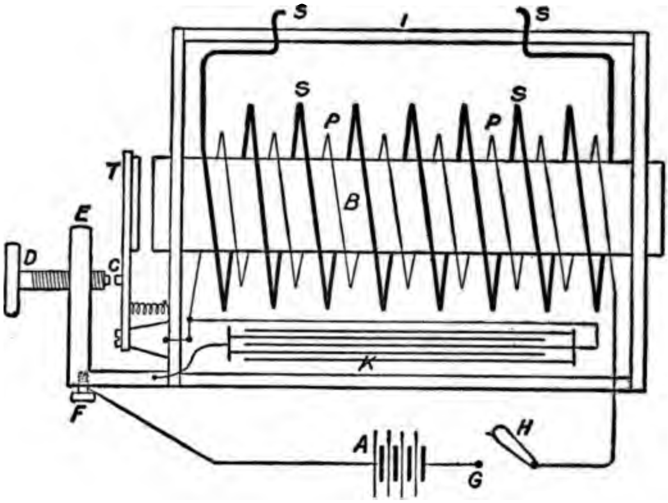


Fig. 26d.—Sectional diagram of a typical induction coil for gas engine ignition. A, the battery or other source of current; B, the core of the coil; C, the vibrator carrying a contact tit at C, and the iron armature at T; D, the battery terminal adjusting screw for making circuit through the tit at C on the vibrator, as it swings back from a contact with the core; E, the post holding the terminal screw, D; F, retaining screw for battery wire; G, terminal of the battery to be in or out of circuit according to the position of the switch, H; I, the case containing the coil and condenser; K, the condenser; P, the primary winding of the coil, in circuit with the battery through the contacts at C; S, S, S, S, the secondary coil and terminals; T, the iron armature on the vibrator.

Construction of the Jump-Spark Coil.—In making a jump-spark coil, it is common to localize and concentrate this magnetism caused in the wire by the flow of electric current by winding the wire around a core just as in the primary spark coil except that the core is usually smaller and the layers of wire fewer. The average jump coil has a core four or five inches long, and between ⅝ to ¾ inch in diameter, which is usually wound with two layers of No. 18 magnet wire. This small amount of wire permits a very ready passage of the electric current, so that the drain on the battery is severe, unless the flow of current is limited by a vibrator or breaking means of some kind, as will be described

later. Around this core, so as to be exposed to its magnetic effect, is placed a half mile or sometimes a mile of very fine wire, usually about No. 37 American wire gauge (.004 inch), which forms the secondary coil. Generally speaking, the induced current is said to be formed in a wire parallel to the primary circuit, and while this effect is true, it applies to such a small degree that the distinction between these coils, in the matter of length, must be kept in mind, the primary coil being but a few feet in length, while the secondary coil is many hundreds of feet. This difference in wire size, and in length, and number of turns, is what causes the difference between the quality of current in the primary circuit and that in the secondary. The primary current in a jump coil is usually about 10 amperes intensity, at four, six, or possibly eight volts, while the secondary impulse is of extremely low amperage, at 30,000 to 50,000 volts, or even higher.

Reasons for Low Efficiency.—It is very generally acknowledged that a small-sized transformer, like the common jump-spark coil, is not efficient, and probably loses 50% of its original electric energy, so that the 60-watt current used to produce the spark loses half its ability in the transformation. This, divided by the number of volts of the jump-spark, would show an almost negligible amperage. It must be remembered, however, that the ordinary jump coil does not permit the primary current to flow for a long time. The large flow is required, but, as quickly as the core is properly charged, it is usually interrupted by a vibrator or moving contact of some kind, which keeps the current broken a much longer time than it is connected. Thus, instead of a current of ten amperes, many coils operate on .1 to .2 ampere, and a coil which uses more than half an ampere is considered wasteful. This use very naturally varies according to the number of cylinders which the coil may be supplying, it being evident that a single coil, supplying four cylinders, will require four times as much current as if it supplied one cylinder only.

Cause of the Inductive Effect.—The induced current in the secondary wire is, as has been shown, not entirely caused by the primary wire being parallel to it, because the difference in length between the two wires does not permit them to lie parallel for any great distance. Coiling both of them around a common center brings many coils of the secondary wire into a position parallel with the primary, at greater or less distance. However, without the core, in which to store the energy of the current, the inductive results in the coil would be very slight. The effect of the primary winding, and of the current flowing through it, is principally to charge up the core of the coil, and, having charged this, the primary circuit is then suddenly broken, and the core permitted to discharge. Very naturally, the discharge would simply increase the small arc or spark at the break in the primary circuit, if some further provision were not made.

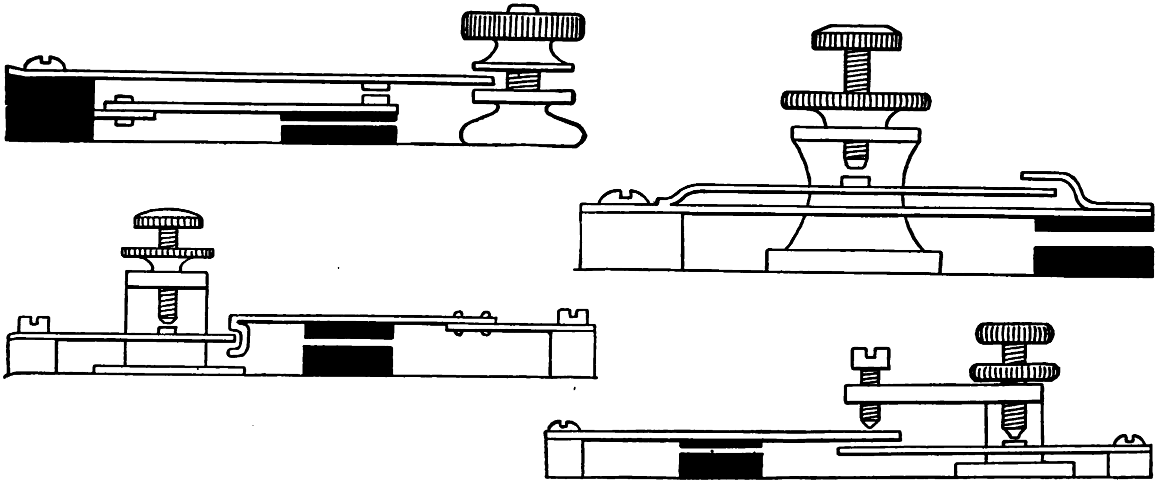


Fig. 26e.
Fig. 26f.

Fig. 26g.
Fig. 26h.

Figs. 26e, 26f, 26g, 26h.—Four familiar forms of induction coil vibrator showing various arrangements of double vibrating leaves designed to achieve the ends of free vibration and adjustable contacts on the back positions of the vibratory movement. The double vibrating leaf is preferred by many designers to the simple form shown on the section of a typical induction coil (Fig. 26d) because of greater ease of movement and of adjustment.

Use of the Condenser.—In the primary ignition system, this primary arc is used for ignition purposes, and it is desirable that the coil increase this arc as much as possible, so that its ignition value may be high, but with the jump coil this is not desired. On the contrary, it is necessary that no spark whatever should occur at the break in the primary, but that all sparking effect and all electrical discharge should be at the gap in the secondary circuit, which is formed by the spark plug points; because this is where the spark and ignition effect is wanted. Largely to prevent a spark at the break in the primary circuit, a condenser is employed. This condenser is a simple affair, depending for its value upon the one fact that electricity will flow off a point better than off a flat or large surface. All students of static electricity know that the sparks between two fine points are small and rapid, whereas those between two balls are large and far between even when the source of electrical energy is the same. The condenser consists simply of two or more flat surfaces, instead of the balls commonly used in the static spark experiment just mentioned. These surfaces are placed as closely together as possible, usually with nothing but paraffined paper between them, and one surface is connected with one end of the primary circuit, the other surface with the other end.

Operation of the Condenser.—When the primary circuit is broken, the electricity does not jump across the points, but, instead, apparently spreads itself out all over these flat surfaces. This causes the charge to be so thin and impotent at any point, as to be unable to pierce the insulated paper lying between the surfaces. Having this large surface on which to spread itself, it does not jump any appreciable length of gap at the breaking point, so that, when a jump coil is properly working, there is almost no spark whatever at the vibrator or breaking points. The effect of this spreading-out of the electricity on the flat surfaces of the condenser, is that the coil, and its core, does not discharge at the gap in the low tension circuit, but expends its energy discharging through the secondary, or induced circuit, with the result that considerable spark is formed at the spark plug points.

Characteristics of the Jump-Spark.—The above-description of this action is not offered as being in all points technically sufficient, but rather as being an understandable explanation of the phenomena, nearly enough correct to meet all requirements. Let it be understood that what is seen as a single spark is not a single spark, but really a succession of sparks, commonly termed an oscillating discharge. Just as lightning is often seen to flash from the clouds to the ground, and back again, so a jump-spark is composed of a dozen or possibly a hundred discharges, each passing through the same hole or path in the air, and appearing to the observer as a single spark. No one of these discharges is very *hot, but the friction* of this large number of discharges heats

the particles of air, in or near to the path to a white heat, and ignites any contained combustible material. If a blast of air be directed upon a fairly long jump-spark, the original hole or path opened will be blown away from the spark points, and a second or third hole necessarily opened, before the discharge is completed. The result is that what is apparently several sparks will be seen by the observer. If one point be rapidly moving and the other be a wide plate, a similar effect is produced, and the oscillations are scattered along the path of travel of the point until the spark is apparently spread out into a fairly wide-lined sheet. This clearly shows that the discharge is composed of a large number of sparks, instead of a single spark.

Construction of the Condenser.—The condenser is usually composed of two sheets of tin foil with a sheet of insulating paper between them, rolled up into a compact form, or of a number of smaller sheets of tin foil alternately connected to either of the two terminals, and separated by sheets of paper between. The one series is connected together to one end of the primary wire, while the alternate series of sheets are connected together to the opposite end of the primary wire. The exact arrangement of the condenser is a matter of choice with the designer; the main requirement being to have the sheets as closely together as possible, and yet separated by a sufficient insulation to prevent the passing of the spark. If the voltage of the primary current is very high, the thickness of the insulating paper is increased, and, for quite high-tension work, the condenser may be made with glass sheets for insulating purposes, instead of paraffined paper. These glass sheets then become, in effect, Leyden jars. These sheets differ from the Leyden jar, however, in that, while receiving a charge, they do not hold it, but at once balance their tension by discharging back through the primary coil which connects the tin foil on the opposite sides. This allusion to the Leyden jar is made to bring out the fact that the charged surfaces of the condenser do receive and hold the electrical energy instead of allowing it to pass, just as does a Leyden jar, which will serve to store up quite large amounts of electricity under favorable conditions.

General Jump-Spark Conditions.—We have now seen that the jump-spark coil consists of a primary circuit, a core, and a secondary circuit. Also that the secondary circuit is not a closed circuit, but terminates in a gap at the spark plug points, and that the primary circuit is almost closed by a condenser, and when a spark is required, is closed through the battery, or electric source, and through a circuit-breaker. This circuit-breaker is commonly called a vibrator, and its object is to break the circuit as quickly as possible, just as is done in primary circuit ignition. The reason for this sudden break is evident. If the circuit is fully closed and *operative*, the full flow of electrical energy takes place, but, *just as quickly* as the circuit is partly broken, the resistance,

or inability of the electricity to pass the joint, lessens the amount of the flow, so lessening the charge of magnetism in the core. The result is that the spark produced is much smaller than would be produced with a sudden break. The spark size also varies inversely as the speed with which the circuit is broken.

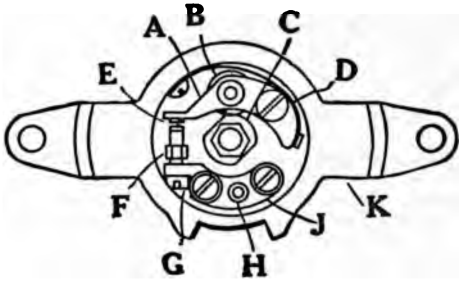


Fig. 26j.—A typical form of primary circuit-breaker for use on a high-tension magneto-generator, showing parts essential to all such apparatus. Carried on a common base plate are: A, a pivoted arm or lever carrying B, a hardened steel roller, which bears upon the face of the cam, C, carried on the end of the armature shaft, and breaking the contact between the points at E, whenever the rounded surfaces of the cam come into contact with roller, B. The contacts, E and F, are normally held together by the pressure of flat spring, D, when the roller bears upon a flattened portion of the cam. G is a screw for adjusting the position of F, consequently, also, of the contact between E and F. H is a thumb nut for securing the front cover of the contact-breaker frame; J, the bottom contact block into which its bolt passes; K, the frame of the contact-breaker having arms for attaching shift links. By rotating the frame, K, through a certain fixed arc the spark may be timed accurately, either advanced or retarded. If the cam rotates to the right (clockwise), moving the frame in the same direction retards the spark, by causing the opening of the circuit to occur later, etc. The proper point of contact between B and C, consequently of separation between E and F, is when the armature inductor flange is in line with the pole pieces, and the primary current is at its greatest intensity. The break at point causes the induction of a secondary current of the maximum intensity, thus putting the full strength into the spark. Sparking is prevented between E and F at breaking by connecting the condenser in the primary circuit.

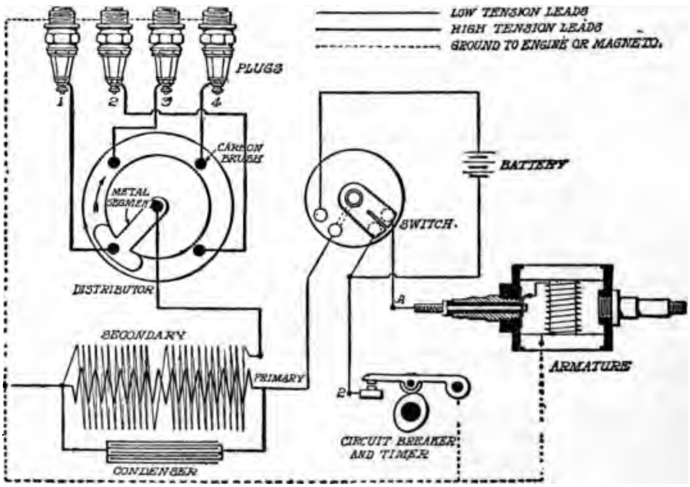
Hammer-Breaking Devices.—On this account, preference is given to the hammer-breaking device, which actually knocks the connecting points apart. This device is quite commonly used in most all jump-spark apparatus, and consists of an adjustable point, platinum-tipped, and a movable spring-carried point, also of platinum. In addition to this spring-carried point, there is a heavier portion, which may be called a hammer. The movement of the engine lifts the hammer, bringing the platinum points together and permitting the current to flow, and after a suitable period the hammer is permitted to fall; and, having been lifted some distance above the spring-carried point, it falls some distance and gains considerable speed before it strikes the spring, and so hammers or drives the two points quickly

apart, making a very sharp break, with resultant good spark. Various methods of operating this hammer to make, and relieve, or break, the contact are used. A common one is simply a cam on a revolving shaft, but in the Rhoades and in the Atwater-Kent systems a trip is used to operate the hammer. This trip is set into actuating position by the motion of the engine and at the proper time released. It is thrown under the hammer by a spring and in passing under it lifts the hammer, making the circuit, and instantly permits the hammer to drop, breaking the circuit. Since the trip is of a constant weight, and is moved by a spring, its action is the same each time, regardless of the speed of the engine. The contacts remain together only long enough to permit the trip to pass under the hammer, and thus the amount of cuncent used, and the amount of charging of the coil, is the same each time, provided the current strength is the same. This arrangement makes a very economical system, and one well adapted to jump-spark ignition service.

Other Forms of Interrupter.—Several other methods of securing economy are used. One of these is the electrical system, by which the circuit is connected and broken by a cam on the engine-shaft during a certain fairly long portion of the engine shaft revolution, but, as soon as the circuit is connected, a magnetically-operated vibrator on the coil breaks the circuit by drawing the hammer away from the points, knocking them apart. In this case the hammer normally is lifted by a spring, and causes the points to remain in contact all the time, except when drawn away by the magnetism of the charged core of the coil. If no further provision than this is made, the hammer will be again lifted by the spring, as quickly as the core has discharged its magnetism, and freed the hammer from its pull. The result of this is to produce a vibrating movement of the hammer, so long as the cam keeps the circuit closed. It will be noted that, with such a system, there are two breaks in the circuit, one of them being at the vibrator, which is placed in parallel with the condenser, and the other being anywhere in the primary circuit, as may be convenient.

Auxiliary Core Arrangements.—It is evident that the hammer will remain down against the core of the coil, so long as magnetism exists there in sufficient strength to hold it down, and, therefore it is evident that a small second magnetic core may be provided to hold down the hammer, as long as the original contact exists at the engine shaft cam. This is done in the Noxon and Delco, and some other systems, for additional economy, and it results in producing a single spark only at each connection at the engine cam. The holding coil is of very fine wire, so that a very slight amount of current passes through it. On *this account* its core does not become charged so quickly *as the main* core, and, therefore, it does not pull down the

hammer, and break the circuit, until the main core has already accomplished this action. Further, being small, its power is smaller than that of the main core, and it is doubtful if it would suffice to pull down the hammer, were it not assisted by the main core. But when the hammer is once brought down close to this secondary core, since magnetic strength increases inversely about as the square of the distance, it is evident that, although very small, it suffices to hold the hammer until the circuit is broken. In the Noxon coils an additional post or switch is often provided, so that this holding core and its coil may be disconnected at will, and, when disconnected, the coil becomes a vibrating coil but usually a single spark is made at each engine sequence.



SPLITDORF

Fig. 26k.—Typical system of ignition circuit using a low-tension magneto, with a chemical battery for starting, a circuit-breaker on a timed shaft (no vibrator being provided on the coil), a wipe-contact distributor, and a rotary switch for cutting out the chemical battery when desired. The circuit-breaker is normally in series with one side of the battery, but is to be thrown in circuit with the magneto only through the proper contacts at the switch. The connections of the spark plugs in the cylinders show the proper arrangement of the leads for a firing order of 1, 3, 4, 2.

Primary and Secondary Sparks Compared.—The impression exists that the jump-spark system, with its buzzing coil and shower of sparks, is better than the make-and-break system, because if one spark does not fire the next one may. This impression is erroneous. The speed of the engine is usually so rapid that, if the first spark does not ignite the charge, the piston will have passed dead-center, and moved downward, so far that the next spark will not find a

compressed mixture, and will very certainly fail to ignite. In short, one spark will do all that can be done, and if the mixture is not right, or, for some similar reason, the one spark fails, the next one will not be in time to be of service. This is easily established by timing the rate of vibration, and calculating the piston travel in that time. One must not, however, confound this single spark with two sparks produced simultaneously. Gunnery experts claim that a charge of explosive is more powerful, if detonated, than if simply fired; and it is certain that an engine with a big spark, or with two sparks at once, will usually show more power than if but one spark is used. Prof. Lucke has shown very conclusively that there is in an engine cylinder such a thing as an "explosive wave," but just what it is, and why it occurs, we do not know. Moving the spark plug from one location to another often varies the running of an engine. These differences, however, are minor ones. The average user need not greatly concern himself with them. A single spark, and a big hot one at that, is what he should see that his engine gets. Further than this, he need scarcely concern himself, except, of course, to see that the timing is proper for the conditions.

Spark Timing.—While, in general, the spark should occur at the upper dead-center, the exact position should be found by trial. The spark advance should be under the control of the operator, and he should frequently test to learn if a little earlier or later will help his power. A hot engine, a rather fat mixture, a low speed, and several other conditions, tend to hasten combustion, and require less spark advance than a cooler engine, a leaner mixture, or a higher speed.

Spark Governors Useless.—Many designers have worked out and applied spark governors, carrying out the thought that the spark should be advanced as the speed increases. These devices have not found the recognition that was expected, and so have not been largely copied. In fact, most builders who once used them have since abandoned them entirely.

Conditions of Spark Timing.—The spark position does not depend on speed alone, but on several features, of which speed is but one. As the speed increases the compression increases, to some extent, so that the flame spreads faster and less advance is needed. Some first-class makers provide only two positions for the spark; one a late position for starting purposes, after which the spark is set at an average forward position, and allowed to remain there. Magneto-users think that the larger spark, produced by the high speeds of the magneto, largely compensates for the lack of advance, and undoubtedly this is the case. It is a well-known fact that magneto ignition requires less spark advance than battery ignition, and part of this is due to the

spark size, but much is due to the more certain action of the magneto. The magneto spark, like the make-and-break spark, is produced without much, if any, lag. In fact, the magneto breaks the circuit at a certain point in the engine-shaft revolution, and the spark occurs at once, just as the piston-operated make-and-break spark is produced. So there is no need for advancing means, to make up for the lag of the sparker parts. And it is this lag that requires the most advance. Where, by a simple test made by the aid of a spark-locator, the magneto shows no lag, the single spark mechanism, used with a battery, may show as much as 60 degrees of lag, or even more. The spark advance lever, therefore, is not largely for the purpose of advancing the spark, but rather to advance the spark timing mechanism, so as to insure that the actual occurrence of the spark, when wanted.

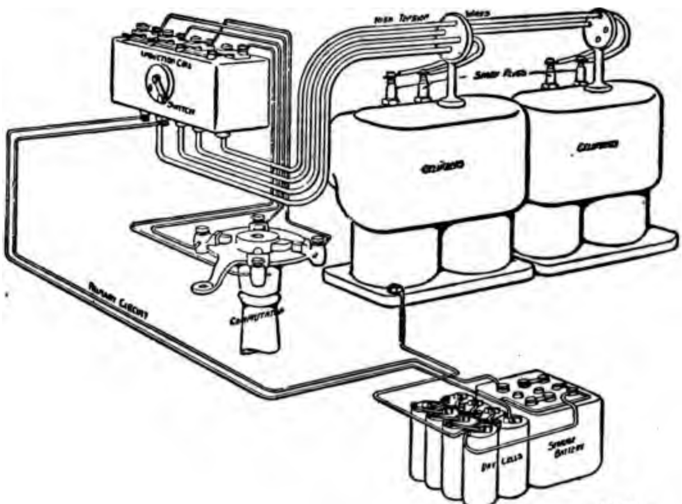


Fig. 261.—Typical arrangement of the circuit wiring for a four-cylinder engine using a dry-cell battery for starting and a storage battery for running ignition. As may be seen on tracing the connections, both these sources have one side grounded to the metal of the engine, the other side of both being led to the switch on the coil box, and by this means capable of being thrown in or out of circuit as required. The coils have vibrators. Hence, no circuit breaker is used.

Reasons for Retarding or Advancing Sparks.—With the full understanding that the timing-lever is not a reliable gage to the spark position, let us consider further the actual spark position required. If the engine is slow running, the ignition and combustion of the gas has ample time to take place, and it is not necessary to ignite early. If the engine is kept quite cool, and the charge is ignited at dead-center,

the heat which is produced, and the pressure which it causes cannot do work, until the crank-pin has reached a more favorable angle, by which time the heat may be largely absorbed by the cylinder walls and the amount of work done be very little. Retarding the spark will undoubtedly assist such an engine to deliver power. But if the engine is running fast, and the mixture is not of the best, considerable time may be required to complete combustion, with the result that the piston has made part of its stroke, and lost much of its opportunity to work, before the full energy of the fuel has been converted into heat, and put into working shape. With a fast-running engine it is, therefore, considered best to ignite far enough ahead of dead-center to allow practically full combustion before the piston starts downward. Then the highest pressure is available, and the piston starts downward with the full opportunity to use that pressure, while the gases by expansion insure great economy.

Economical Operating Conditions.—In a gas engine, just as in a steam engine, the great economy of operation comes, not from carrying the boiler pressure (the combustion) to the full end of the stroke, but rather in cutting off (completing combustion) as early as possible, and, by expansion, getting out of the gases all the work possible. While it is true that the Diesel engine admits fuel and carries the combustion quite late after dead-center, it is not to be included in this class, not being used for auto work, and not operating on a similar cycle. In general, the spark should be variable, unless the means of production is such that speed does not increase the lag, in which event the faster compressions allow less time for loss of heat, and so partly compensate for advance. The spark should occur at as early a point as does not interfere with the power of the engine. This to allow the combustion to be completed, and all heat ready for use, when the crank passes over dead-center, and can utilize it.

Throttling and Spark Retarding.—There is no objection to throttling the engine without retarding the spark, so long as one does not allow the engine speed to fall so low that the fly-wheel will not carry over, or that "pounding" occurs. Throttling a 4-cycle engine reduces compressions, and often renders the mixture less fat, both of which effects slow the combustion, and serve much as a retarded spark. But care should be exercised on hills, or in hard pulls, that the spark be not kept too much advanced. Full charges and a hot engine need very little, if any, spark advance under such conditions, and the advance that served very well on the level may cause the spark to occur too early, and much negative work results. The engine will labor much harder than it should, and may stop dead, being unable to continue against both the load and the back-pressure, which the ascending piston encounters with the too early *spark.*

Spark Control and Engine Speed.—Some drivers use the spark lever to control the speed of the engine, and, while this is possible, and can be used in an emergency, it is now an obsolete practice. It uses fuel needlessly, overheats the engine, tends to imperfect combustion with much odor, may burn the muffler and pipes, and is a brutal way of doing something, which the throttle only is intended to do. This practice is one of the principal causes of pitted and warped

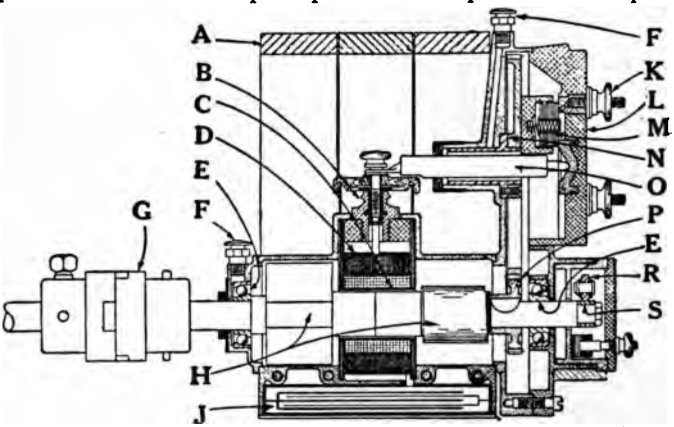


Fig. 26m.—Sectional diagram of a type of high-tension magneto-generator having a stationary coil wound in annular form, and excited by rotating inductors in front and behind it on the armature shaft, which turns through the eye of the coil. These two inductor rotors are shaped approximately like the H-shaped armature of the common magneto, and are set so that the webs supporting their flanges are at right angles to one another. This is shown in the diagram. Here: A indicates the magnets; B, the safety spark-gap; C, the primary winding of the coil; D, the secondary winding; E, E, ball bearings on the armature shaft; F, F, oil cups on the shafts; G, coupling for connecting to the engine shaft; H, inductor rotors; J, the condenser; K, secondary terminal; L, distributor; M, rotating brush on distributor; N, gear (2 to 1) carrying the distributor brush; O, high-tension bus bar; P, driving pinion on the armature shaft, rotating at the speed of the engine shaft; R, roller on the lifting arm of the circuit breaker; S, cam on the armature shaft for engaging roller and lifting arm of contact breaker. The advantage to be found in the use of this type of generator is, as claimed, the production of a perfect sine wave, having a gradual rise to maximum.

exhaust valves, with consequent frequent need for regrinding. There is less danger in advancing the spark, but, if advanced too much, the engine does negative work and generally "pounds," which involves needless work on the bearings, as well as being offensive to mechanically trained ears.

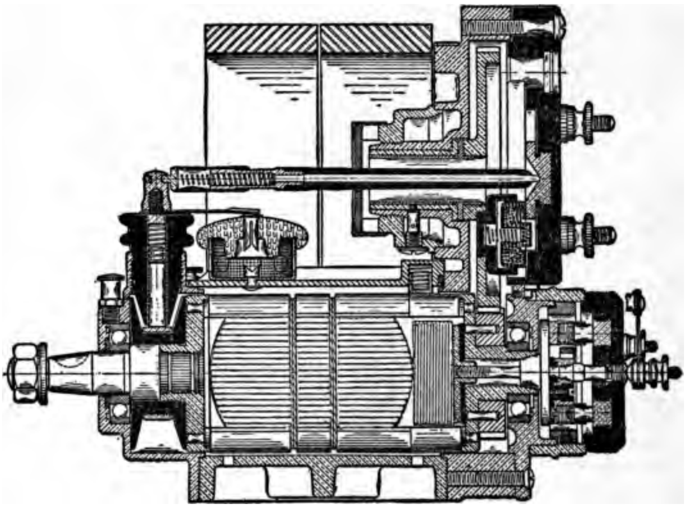
Variable and Fixed Ignitions.—In this country variable ignition is common, but in Europe the fixed spark is much in use. The probability is that we shall follow the Europeans in this respect, as we have in many others, for the

reason that we can see the things which strangers do much quicker than those close at hand, if for no other reason. But, so long as we use variable ignition, the set of the spark must be learned by the driver. If he will experiment with it, when opportunity occurs, he will soon learn what results follow and need no instructions. With the ignition, as with the throttle, the engine should be given time to follow the adjustment. Throwing the spark well ahead will generally produce pounding until the engine has had time to catch up. Throwing it back suddenly does not produce such apparent results, but even here gradual action is best. The best driver is the one whose car glides, rather than jumps. The engine should grow into greater or less power, rather than jump into it. It is spectacular evidence of power to race the engine, until it nearly jumps out of the vehicle, and then let in the clutch with a jerk, and slide the wheels in getting under way, but it is hard on the mechanism, and conducive to repair bills. This all well informed drivers understand. But the pounding of the engine, due to overmuch spark advance, the use of the spark lever for controlling, instead of the throttle, and similar abuses are likewise the marks, either of the novice or of the man who hopes to impress the novice.

Practical Methods of Finding Spark Positions.—Having described the general principles which govern the timing of the spark, more specific instructions are now in place. Generally, the spark is spoken of in relation to the fly-wheel and the crank-pin, to which the connecting-rod is attached. When the crank-pin is up, and the piston as high as it goes, a mark is usually placed on the fly-wheel, to indicate the upper dead-center. Sometimes a pointer is provided on the frame, which projects near to the fly-wheel, and the mark is made at this pointer, when the wheel is in proper position. At other times the most convenient cross-bar or frame member is used as a guide. If the fly-wheel is not marked, it is easy to mark it as follows: Turn the crank-pin some 40 or 50 degrees away from dead-center, and carefully measure the position of the piston from the head of the cylinder. (A wire stuck into the spark plug hole or priming cock opening will indicate this position very accurately.) Then mark the fly-wheel with a lead pencil at this point. Next, turn the crank-pin to the opposite side of dead-center, and, with the piston at same distance from the top, again mark the fly-wheel, and with a tape line find the mid-position, between these two marks. This is the place for the exact dead-center mark. These measurements can be made much more accurately than one can find dead-center by feeling for it, because, for some degrees on either side of the actual center, the vertical motion of the piston is so small as to be very difficult to recognize. This is mostly due to the fact that the crank-pin is travelling across the line of piston travel, instead of with it at this time. It is also due to the fact that the bearings may not be perfectly

adjusted, and that a very slight loss of motion permits much movement of the crank-pin, without corresponding movement of the piston.

Finding Lower Dead-Center.—The opposite dead-center is used also for valve-timing, and can be found in the same manner, or can be located by the tape line measure laid around the fly-wheel periphery. Care should be taken to mark the cylinder number on the fly-wheel at this point lest an error be made and the dead-center for one cylinder used



SIMMS

Fig. 26n.—Sectional diagram of a type of high-tension magneto-generator having the high- and low-tension coils wound on the rotating armature, as in the common type of low-tension generator. As shown here, the coil is wound on a spool with its length at right angles to the line of the armature shaft, within a cage formed between the flanges of the H-shaped armature. The condenser is also set within the space between these inductor flanges. The other parts may be recognized by comparison with the descriptions given in connection with previous figures.

for that of another. In general, the forward cylinder is considered No. 1, the others following in rotation. If the engine lies across the vehicle the right hand cylinder is No. 1. This practice may not be universal, but is quite commonly followed. If the fly-wheel should ever be removed, care should be taken to put it back in same position with reference to the shaft, or else the markings may be carried wrongly, and much confusion result, when timing the parts.

Importance of Accurate Timing.—This need for care in *the finding of the* dead-center indicates the need for care in

timing; not only the spark but the valves. No engine can give its best power, if it is not timed alike in all cylinders. The engine that has one cylinder early, and another late, runs with a limping exhaust, which indicates this uneven action, making very audible the uneven application and production of power. If the spark is right in one cylinder under such uneven timing, it is too early, or too late, in another cylinder. This means loss of power that might better be developed; also, that there is no certainty to the spark advance position, since changing may better the cylinder that was wrong, but make the right cylinder worse, with no apparent difference in the general results. These facts apply to either system of spark ignition, although there is more chance for difference with the jump spark than with the make and break, because of the greater opportunity for lag in the former.

Tuning the Coil Vibrators.—To overcome these differences, the various vibrators should be tuned as nearly alike as possible, if a multiple vibrator coil is used. Otherwise, one will be slow, and the other fast, with many degrees difference in the actual position of the spark. Not only may the differences in time cause faulty action, but the vibrators may not act alike. A rough point or dirty contact may slow one vibrator, when the others are working correctly; or, since the strength of the magnetic action varies as the square of the distance, or nearly so, one vibrator may be held down longer than another. This may often be remedied by pasting a piece of paper on the end of the core under the vibrator, so it may not come in direct contact with the metal core, thus preventing the vibrator from sticking down by the action of the residual magnetism of the core, as sometimes happens.

Coil Defects and Care.—Faults in timing with a multiple-cylinder coil are often due to defects in the coil. While the average coil is not complicated, the parts are so delicate that the usual workman will damage some part, in trying to get at the fault. To preserve the parts from damage it is usual to imbed them in paraffin, or similar wax, and any attempt to dig them out of this usually results in broken wires or bared insulations. To remove the wax with no danger, unscrew the box bottom and place the box over a pan in an oven, in which the heat is not much greater than the melting point of the wax. After sufficient time to permit heating the mass, the wax will flow out and leave the parts in sight and quite accessible. Generally, however, it is best to send the coil to the coil-maker, who can repair it better and quicker, and is usually willing to do so.

Single Vibrators and Single Coils.—Because of these difficulties in spark timing with multiple coils and vibrators, inventors have tried to do away with the multiple parts, and substitute single vibrators, or even single coils. The

single vibrator is placed in the grounded end of the circuit, while the other end of each primary wire goes from its respective coil to the timer. The vibrator is actuated by a small electro-magnet, which requires the same length of time to charge as does the core of the coil. Because of this fact breaking the circuit by this common vibrator acts just as well, as if broken by the magnetism of the coil itself. It is not necessary that all the current should pass through the electro-magnet, but it may be operated by a shunt circuit,

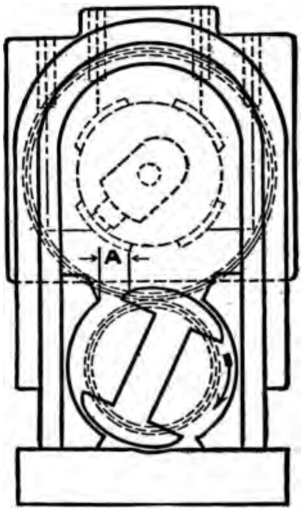


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Fig. 260.—Diagram of the front of a high-tension magneto-generator showing (in dotted circles) the 2-to-1 reduction gears between the armature and distributor shafts; also (dotted) the positions of the contacts, rotating brush, leads, etc. The H-shaped armature is also shown, its position being that proper at head-center on the compression stroke, as measured on the clearance, A, between the tip of the left-hand pole piece and that of the retreating flange, when the armature is rotated in the direction indicated by the arrow. If the rotation is in the opposite direction (counter-clockwise), this distance is measured from the tip of right hand pole piece. This distance, A, varies from about .55 to .83 inch for usual commercial magnetos.

which takes only a small part of the current, and so does not interfere appreciably with the coil. Because of this single vibrator controlling all the coils it is usually termed a "master vibrator."

Single Coil Arrangements.—Much of the difficulty of multiple spark timing is avoided by the use of a single coil, and a multiple means of breaking the current at the proper time for each cylinder, with means for distributing the spark produced to the proper cylinder. This timer and *distributor arrangement* has found much favor, because of

its cheapness, as well as because of its ability to spark all the cylinders alike, if the operating cams are properly spaced.

Need of Accurate Timers.—Perhaps in no place about an engine is there greater need for careful work than in this spacing of the cams, or contacts. Engine-makers who would not think of allowing a crank-shaft to pass, unless it was properly spaced and balanced, will buy timers in the open market and use them, without even testing, to see if they

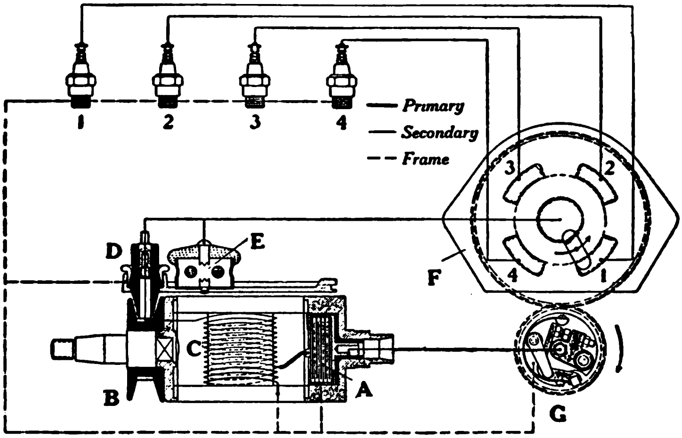


Fig. 26p.—Diagram of an ignition circuit using a typical form of high-tension magneto. All the parts, which are arranged upon a single frame are here shown in approximately correct relative positions. On the rotating armature frame are the parts: A, the condenser; B, the insulating ring carrying the collector ring taking the high-tension current from armature, C, and delivering it to carbon brush, D. E is the safety spark gap, provided for the purpose of allowing a jump for the high-tension current, in the event that any one of the plugs is disconnected, and thus prevent burning-out of the insulation of the windings through excessive current passage at that particular point in the rotation of the armature. F is the current distributor on the second shaft (driven 2 to 1 from the armature shaft, which rotates at the speed of the engine shaft). The distributor contacts are shown at 1, 2, 3, 4, the brush on contact, 1, and the direction of rotation indicated by the arrow. The plugs are shown in the order of firing, not in the correct arrangement in the engine cylinders. G is the primary circuit breaker, which is carried on the armature shaft and rotates with it. This shaft also carries the driving pinion, which meshes with the gear carrying the contact brush of the distributor.

are carefully made. The average timer is not a large device, and a very small distance on the working surfaces may be equal to a large angular distance on the crank circle, with the result that one cylinder fires considerably earlier, or later, than its mates, with noticeable difference in sound, as well as in power. It is manifestly impossible to properly adjust the spark timer lever on an engine, in which

the cylinders are fired at different points with respect to their compression dead-centers. One may fire too early, while the next is firing too late. When one thinks of the many things that may affect the ignition time of a multi-cylindered motor, one wonders, not that some of them do not run evenly, but, rather, that so many of them run as well as they do. It speaks volumes for the quality of work turned out by modern auto-makers.

Effect of Mixtures, Manifold Shapes, etc.—But, even after all care has been taken by the maker to get the mechanical parts right, there is still some difference in timing, due to the differing qualities of mixture which may reach the various cylinders, as well as to the shape of the manifolds, or similar causes. It will be seen, therefore, that each engine must be timed by the operator, as he drives, and that the best compromise position of the sparks must be sought for. While, as a general rule, a considerable range of timing is permissible, the careful driver will frequently feel of his spark lever, to be sure that he is getting the best results from any given engine speed or carburetor adjustment.

CHAPTER XXVII.

CLUTCHES AND TRANSMISSIONS.

The Limitations of the Gasolene Engine.—No problem has proven more elusive, no solution more difficult, than the transmission problem of the gasolene motor vehicle. This has been due partly to the fact that the gasolene engine is greatly limited in its capabilities. It cannot start under a load, and, even when started, it does not develop full power, unless running at a high speed. For example, an engine rated at 15 or 18-horse-power will quite likely show an increase nearly proportionate to the speed, until the maximum power is reached, probably at 1,500 revolutions per minute. Such an engine will run well up to twice this speed, but its power decreases, because of its inability to take in full charges and to properly work them after the point of maximum power has been passed. The speed of maximum power depends largely upon the design of the engine, the size of the valves, the quality of the mixture, the time of ignition and many similar features. Consequently, the above figure is not given as a limit, but rather as a fairly common example. From this illustration it may be seen that a 15-horse-power gas engine, at 100 turns per minute, is not doing much more than overcoming its own friction, and that its power is so low at these slow speeds as to be practically ineffective for vehicle propulsion.

The Clutch and Its Function.—Because of these operative limitations, all automobile gas engines are fitted with clutches, in order that they may be permitted to run free until well started and warmed up. The power must be applied to the vehicle gradually, so as not to slow the engine down, and thus permit it to transmit energy to the road wheels of the vehicle, and start it moving. Therefore, the clutch for connecting and disconnecting the engine is of the friction variety, which permits the load to be taken up gradually. In steam or electric vehicles, the motor is power-*ful enough to* start both itself and the vehicle from a stand-

still, and, on this account, no clutch need be used; although in some cases clutches have been supplied.

The Need of Mechanical Reductions.—Next, the fact that the engine will not develop full power at low speed necessitates a fair speed of the engine, in order that it may properly pull the vehicle, and since the operator may at one time be driving slowly with light load, or slowly with heavy load, or fast with light load, or in some similar combination, it is necessary that two speeds at least be arranged for. In the lighter and more moderate-speeded vehicles, two speeds forward are sufficient. The first of these, commonly as directly connected with the engine as possible, suffices for all ordinary service; that is to say, as the engine is throttled, the vehicle can be run on this gear slowly enough to get through all ordinary traffic, or fast enough to meet common road conditions. The other is the slow speed for emergencies, requiring exceedingly slow or difficult movement, as in pulling through mud or sand or in hill climbing.

The Need of Mechanical Reversing.—While it is not necessary to reverse the vehicle often, particularly a light vehicle, which may be pushed out of the garage or stable, public opinion so strongly favors a reverse, that few, if any, motor vehicles are built without a reverse speed also. In boat service the engines are usually reversible, but this is not very satisfactory even there, and would be much less so on the road. In motor boats the 2-cycle engine is quite common, but since most automobiles employ the 4-cycle engine, which does not reverse readily, it may be seen that the reversing speed or mechanism is practically a necessity. Here again the gas engine differs from the steam engine or the electric motor, both of which run backward by shifting the valve mechanism or throwing the reverse switch. When more than two speeds are needed, additional gearing must be provided to give this result. From the foregoing, it is seen that there are a number of conditions to be met, and a number of reasons why a transmission is a very essential element in the motor vehicle.

The Sliding Gear.—One of the oldest forms of speed-changing device for automobiles is the sliding gear, in which the driving shaft has one or more driving pinions arranged near to an idler shaft having complementary pinions. On one shaft the pinions are fixed in position, but on the other they may slide lengthwise the shaft, and thus, at the will of the operator, any driven pinion may be slid into engagement with its driving pinion, and the driven shaft operated at a speed proportionate to the respective sizes of the two pinions. To obtain a different speed, the one pinion would be disengaged and another meshed with its respective driving pinion. The cuts make plain several forms of these devices, usually two driven pinions are attached to a single sleeve and moved together, in one direction to engage with one gear

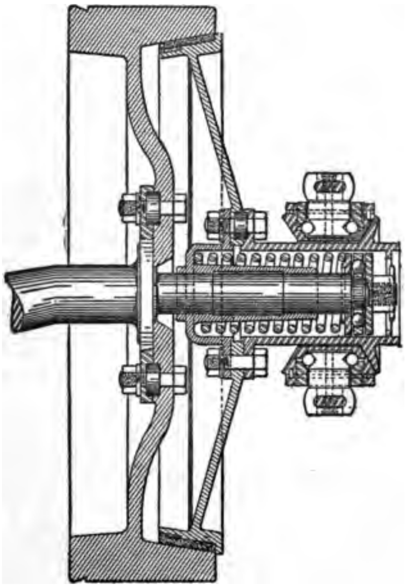


Fig. 27a.

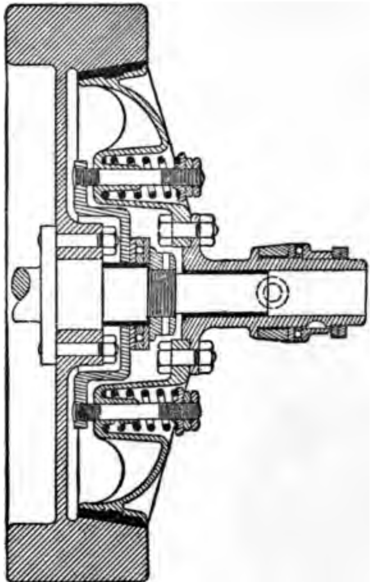


Fig. 27b.

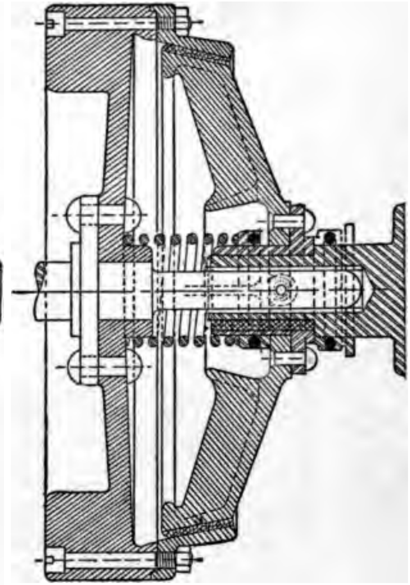


Fig. 27c.

Figs. 27a, 27b, 27c.—Three forms of cone clutch, showing arrangement of cones and retaining springs. The first two are of the external cone type, the third of the internal cone type, in which the "male cone" is pushed inward to disengage it from the cone ring.

and in the opposite direction to engage the other. Such an arrangement of gears permits as many speed changes as are desired.

Direct Drive Sliding Gears.—The form above described is the simplest and one of the oldest forms, but since the final drive is on the second or driven shaft, which is parallel to, and at one side of, the driving shaft, it is evident that a direct drive cannot exist, consequently, these sliding-gear devices place a third or final shaft directly in line with the first or driven shaft, and provide a pair of pinions constantly in mesh between the idler shaft and the third or final shaft. This arrangement permits clutching the driven final shaft with the driving shaft, when direct drive is wanted, leaving the intermediate pinions disengaged.

The Gear Housing.—The sliding gear drive is usually housed and operated in grease, so as to deaden the noise and insure perfect lubrication. It is quite commonly placed in the same housing that encloses the crank-shaft and fly-wheel, or, as in several cases, in the bevel gear and differential housing on the rear axle. The planetary gear transmission is likewise thus placed on the rear axle occasionally. The earlier automobiles did not house these gears and had considerable trouble with them. They were characterized by one of the early French makers as being "a very brutal device but practical." As now made, their perfection of workmanship, housing and controlling has robbed them of much of their clumsiness and coarseness and made them a very serviceable and fairly acceptable form of drive.

The Planetary Drive.—This is the simplest form of speed-changing mechanism using gears, and is particularly favored for light-weight, simple machines, because the whole gear revolves with the fly-wheel on direct drive, and thus obviates the necessity for some fly-wheel weight. It is usually arranged with separate clutches, so that there are no gears to clash, and the whole device is usually housed oil-tight, with consequent little noise and long life. Two general forms of planetary drive are known, the first being simpler in theory than the later and more common form, although slightly more complex to build. It employs (a) a driving pinion on the motor shaft, (b) one or more idlers meshing into this pinion, and (c) a driven internal gear surrounding these idlers and meshing with them.

Planetary Gear Operation.—The action which is extremely simple is as follows:—(1) If by a suitable clutch the device is locked so that the gears may not revolve on each other, the vehicle is driven directly from the engine, the driven part moving at the same speed as the motor shaft. (2) If this clutch is released and the encircling ring, commonly termed an internal gear, is held so that it may not revolve, then the idlers will travel around as the engine shaft re-

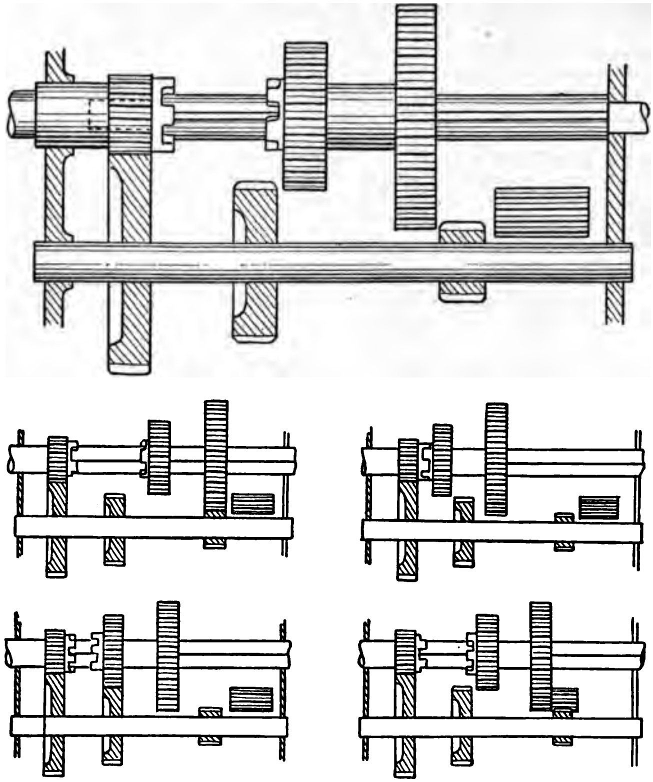


Fig. 27d.—Diagrams of the operations in a type of progressive sliding change-speed gear. As shown in the large diagram, the main shaft is in two parts, that to the left being integral with the clutch shaft, that to the right being journaled into the end of the other. This second part of the shaft is splined, as shown, through most of its length between bearings, carries a sliding sleeve, upon which are carried a small and a large gear. The clutch end of the main shaft carries a small gear, which is in constant mesh with a large gear on the second shaft, which, in consequence, is constantly rotated with the clutch shaft. The first small diagram to the right shows the high speed forward, the direct-drive, obtained by sliding the sleeve on the splined shaft all the way to the left, so that the two elements of the claw clutch engage, and the shaft works as a single unit. The diagram to the left of this shows the low speed, obtained by meshing the large gear on the splined shaft with the small gear on the second shaft, thus driving the large gear and the second part of the main shaft. The lower small diagram on the left shows the intermediate speed, obtained by meshing the larger pinion on the second shaft with the smaller pinion on the splined shaft. The lower small diagram to the right shows the reverse, obtained by sliding the large gear on the splined shaft to the position shown, and driving it from the second shaft by meshing the two with the long idler gear *shown at the right* in all cuts, and which is slid into engagement by a *special lever.*

volves, and, in traveling, will carry their studs or shafts forward at slow speed. Thus if the driving pinion and the idlers are of the same size, the internal gear will be three times the diameter of the driving pinion and the low speed will be four to one, that is, one-fourth as fast as the engine shaft. This is because three turns of the pinion must be made to roll the idlers around the pinion and the engine gets ahead of the driven shaft one turn because the idlers, in rolling around, have fallen behind enough to permit this extra turn. On this account all these planetary devices give an extra turn lost motion to each revolution, or every time the idlers return to their original position in relation to the driving pinion.

The Reverse Motion.—In order to secure the reverse motion, the idler studs or shafts, mounted on a frame or spider, must be held by a suitable clutch from revolving around the main shaft, while the internal or ring gear is

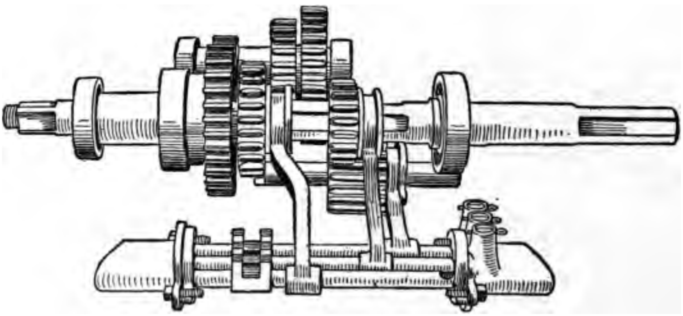
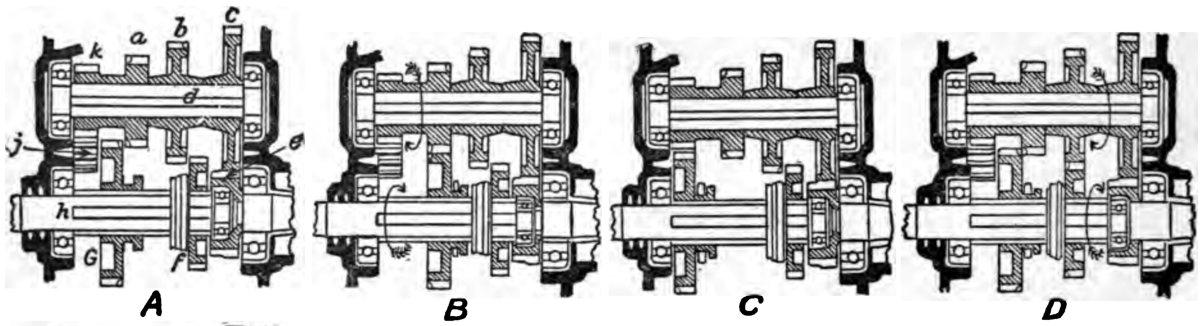


Fig. 27e.—View of a selective sliding gear transmission, showing the sliding selecting rods and arms for sliding the single spur gears on the squared or splined shaft, into mesh progressively with gears on the opposite or second shaft. The gear attached to the arm on the outer selecting rod is shown brought to the position of engaging the clutch on the engine, or clutch, shaft and thus giving the direct drive to the rear wheels by holding the splined portion of the shaft into rigid union with the main driving member and the differential on the rear axle.

permitted to revolve and the driven shaft locked to it. It is self-evident that, if the idlers cannot move, the rotation of the engine shaft and its driving pinion in any direction will carry the ring gear in the reverse direction at the same tooth or lineal speed. That is to say, ten teeth of the main-shaft pinion will carry the ring gear ten teeth in a reverse direction. Thus, such a planetary gear will give a reverse speed three to one or one-third the speed of the engine.

Additional Speeds.—By the addition of a larger or a smaller main-shaft pinion and suitable idlers, a second ring-gear may be driven at a somewhat higher or lower speed, as desired, with the result that three speeds forward and two reverses can be obtained from the planetary transmission, all being free from friction when driving direct. This



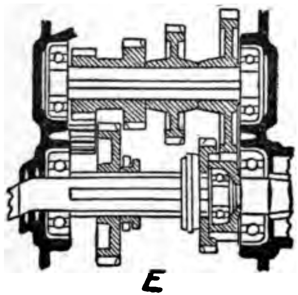


Fig. 27f.—Sectional diagrams of a three-speed and reverse selective transmission, showing the progressive positions of the sliding spurs in giving the several speeds. At A is seen the apparatus in neutral position, in which there is no drive to the road wheels. Here the parts are shown lettered, as follows: *a*, *b*, *c*, *k*, gears on the second shaft, *d*, which is driven constantly from the main shaft pinion, *e*, meshing permanently with *c*. The squared or splined continuation of the main shaft, shown at *h*, is journaled into the end of the clutch shaft, and turns independently of it, transmitting such speeds to the road wheels as are imparted through the meshing of gears, *g* and *f*, with correspondents on the second shaft, *d*. On the second shaft, *c* is the driving gear; *b*, the second speed gear, when engaging with *f*; *a*, the low-speed gear engaging with *g*; *k*, the reverse gear in constant mesh with the pinion, *j*, giving the reverse when gear *g*, also meshes with *j*. At B is shown the meshing of *g* and *a*, giving the low speed. At C is shown the meshing of *g* and *j*, giving the reverse. At D gears, *b* and *f*, are in mesh, giving the intermediate speed. At E, gear, *f*, has been moved all the way to the clutch end of shaft, *h*, engaging the tooth clutch on gear, *e*, thus locking the two sections of the main shaft into one continuous piece, and giving the high speed forward or direct drive.

simple gearing and its housing is usually placed on the engine shaft by the side of the fly-wheel, and requires very little attachment to the vehicle frame, thus contributing to the ends of flexibility and easy assembling. The demand for more than two speeds in the high-powered cars has led to the use of other devices, and the popularity in percentages of the planetary drive has been much reduced of late years, although probably such devices are now made in larger quantities than ever before.

The Spur-Gear Planetary Drive.—The second form of planetary gear, and the most common one, is made up of all spur gears instead of employing an internal gearing. There is the driving gear attached to the engine and two gears of different size attached to drums, which may be held by bands, all three being concentric with the motor shaft. Meshing into these three gears are three pinions all mounted together, and running on a common stud. They must therefore all revolve together. But since they are of different sizes they produce different results so far as motion of the two driven gears is concerned. When the whole transmission is locked as a unit, it turns with the engine, in which event the gears and pinions are inert. This is the usual high speed arrangement. Holding the case that carries the pinion stud causes the pinions to drive the free gears forward, but at a rate depending on the respective sizes of the pairs, and thus produces low speed forward.

Reversing the Spur Drive.—Holding one of the driven gears causes the pinions, studs and case to roll around the held gear, in a direction the reverse of the engine motion, and this is used for the reverse drive. In this reverse action the strains on the teeth of the gears are quite heavy, but they can be strong and give no trouble from this cause. A double set of pinions placed in the case on opposite sides can also be used to secure a balanced effect. The case is usually drum-shaped, and practically oil-tight, so that these gears run in oil, and are thus quite durable. The bands for holding the parts to produce the different speeds must be attached to the frame of the vehicle or engine, but, aside from these, the planetary gear is self supported by its central shaft in its usual form. When running on the high speed, it acts as an additional fly wheel, by adding its weight to the rotating mass. The above covers the general design of the all-spur form, but the details of construction vary somewhat in different makes, particularly in the clutch arrangement, and the means of taking off the power from the respective parts.

The Friction Disk.—Probably the most commonly-tried transmission is the friction disk. This consists of a driving disk on the motor shaft and a driven disk on a second shaft at right angles to it, the edge of the driven disk bearing against the face of the driving disk and being rotated

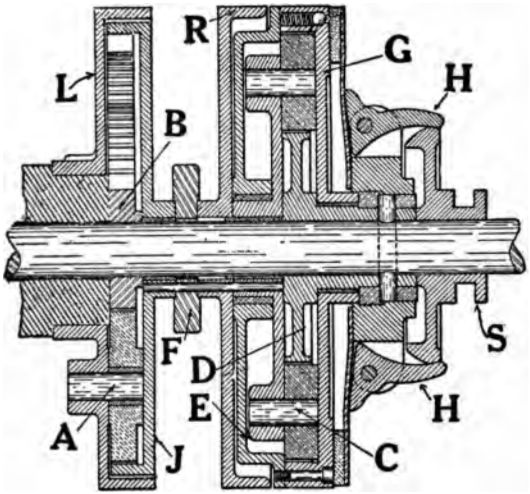


Fig. 27g.

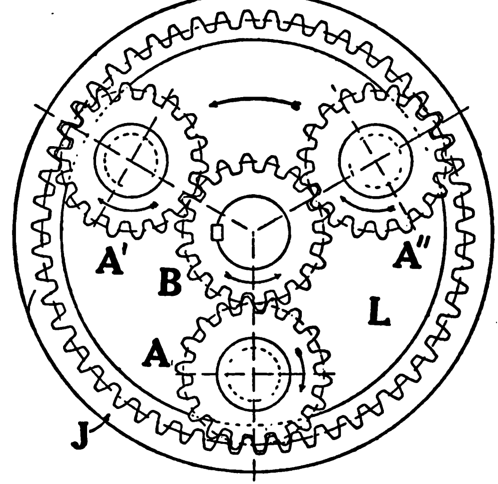


Fig. 27h.

Fig. 27g.—Cross section of a typical planetary or epicyclic transmission equipped with internal gears, showing essential features of construction. B and D are spur gears keyed to the main shaft; A and C are spur pinions engaging them, and G and J are discs carrying internal gears which engage with the spur pinions, A, C, etc. The brake drum, R, and the spider carrying pinion, C, and its mates, is integral with sprocket, F, and disc, J, carrying internal gear meshing with pinion, A, and its mates. The gears, B and D, turn with the shaft, rotating the spider, L, carrying the gear, A, and its mates, and the disc or drum, G, containing the internal gear meshing with C and its mates. Disc, J, and spider, E, do not rotate, because of the fact that they are integral with the sleeve carrying the sprocket, F, which is maintained stationary because of the fact that, on account of the relative positions of J and E, the rotative stress tends to drive it into two opposite directions, and with equal effort. When, however, the drum, or spider, L, is held stationary

(Caption continued at bottom of page 255.)

by the friction between them. The driven disk is further arranged to slide along its shaft, and thus make contact with the face of the driving disk. The cut makes plain this device, which, if well made and properly cared for, is extremely satisfactory. In the words of a pioneer builder of this type of transmission, "It is all right if made right." To this he might have added, "and if properly cared for."

Friction and Pressure Requirements.—Since this form of driving depends upon frictional contact between the driving and driven surfaces, it is evident that these surfaces should be such as will give a high friction co-efficient and yet be reasonably durable, also that they must be forced together with considerable pressure since no available materials offer a friction co-efficient high enough to ensure efficient operation under other conditions. Most makers of this form of transmission have erred in the fact that they did not provide for the excessive pressures required to make the device pull heavy loads. The result was that the frames sprung, the bearings were forced out of line, the shafts bound, and a more or less general deterioration took place, which rapidly put the device out of commission.

Driving Disk Shaft Bearings.—Because of these conditions it is now generally accepted that the driving disk can best be carried on some length of shaft which can be properly supported by bearings and thus resist the pressure against one side of the disk. When the driving disk is attached otherwise than to a straight length of shaft, as for example, attached to the crank-shaft, the working pressure against it generally springs the crank-shaft, and, in time, breaks it. And even during the life of the crank-shaft the service rendered is faulty, because in some directions the crank-shaft is less able to resist the working pressure than in other directions, an objection not to be encountered with the straight shaft, which is preferably to be used.

Varying the Speed.—The driven disk, when moved out from the center on one side of the driving disk, gives a constantly increasing speed to the vehicle, as the contact is

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against rotation by a band or shoe bearing upon its face, the drum, J, carrying the internal gear, is caused to rotate in a direction opposite to that of the main shaft, thus giving the reverse. When the drum on G, carrying the other internal gear is similarly constricted, the sleeve carrying the sprocket, F, is rotated in the same direction as the main shaft, thus giving the slow speed forward. For the high speed forward, the direct drive in cars using propeller shaft transmission, rather than the sprocket, the spool, S, is pressed inward (to the left in the plate), actuating the clutch levers, H and H, and pressing the entire apparatus into one working unit, which turns with the speed of the main shaft, and in the same direction. These movements are shown in the three-circle diagram.

Fig. 27h.—Front, or end, elevation of a planetary gear train such as the arrangement of spur gear, B, keyed to the shaft, pinions, A, A' A", is described in connection with the preceding figure. Here may be seen *hung on spider*, or drum, L, and disc, J, carrying the internal gear.

made farther from the center of the driving disk. The inner contacts are used only for low speed, as for starting or occasional hill-climbing. Thus, it becomes evident that most of the driving is done near the outer edge of the driving disk, and that at this place the pressure is more even and regular, because of the elasticity of the parts. The twisting action between the contact surfaces is smaller also, because the driving disk at this place is large in diameter, and its circumferential curvature is slight for the portion in contact with the driven disk, as compared with the curvature contact nearer the center.

The Conditions of Driving Friction.—While in theory two circles or disks can have but a single point or line of contact, in practice the materials yield sufficiently to permit more or less surface contact. Further, it is evident that of three adjacent concentric circles on the driving disk, the

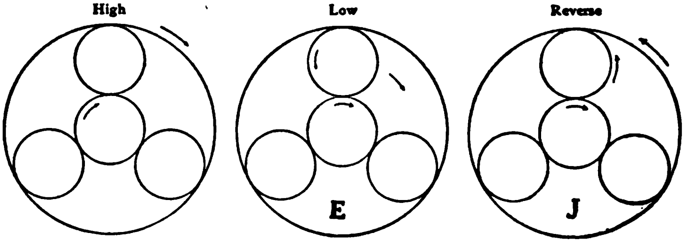

Fig. 27j.—Diagram showing the operation of a planetary transmission, as explained in connection with the foregoing figures. The high speed is obtained by compressing all members into a solid working unit, which revolves in the same direction as the main shaft. For the low speed, the drum carrying the internal gear is stopped from rotation, involving that the spider, E, carrying the spur planetary pinions, in one piece with the sleeve, F, is rotated in the same direction as the shaft, the pinions traveling around on the internal gear, each turning on its own axis. For the reverse, the spider carrying the planetary pinions being held from rotation, the drum carrying the internal gear rotates in direction opposite to the main shaft, the planetary pinions turning on their own axes and urging it around, consequently also rotating the sleeve and sprocket, F, in reverse direction. In the gear here illustrated each spider or disc carries three planetary pinions, although four are often studded on.

outer one travels farther per revolution, and therefore faster, than the middle one, while the inner one travels a shorter distance, and therefore more slowly. It is thus seen that the outer part of the contact surface of the driven disk is driven, by the outer circle, faster than is the inner part of the contact surface, which comes in contact with the inner circle. Since these parts can move only at the same speed, one must slip backward to make allowance for the excess speed of the outer circle, while the other one must slip forward on the surface of the driving disk, in order to catch up with the middle or neutral circle, and thus make allowance for the slower traveling of the inner circle. A little thought will make plain this action, and inspection of any driven

disk edges will show that the fibers of the paper or leather, usually used as the driven surface, lie in the direction in which the slipping or wiping action carries them.

Conditions of Power Loss.—This brief discussion explains the considerable loss in friction at the driving surfaces of friction disk transmissions; also the slipping loss in connection with the "twisting effect," which results from the fact that the driving surface does not come into contact with the driven disk in the same plane, but comes in from one side to the center or full contact line and then passes out of contact with some motion in the opposite direction. This latter motion being backward toward the side from which it came, constitutes a very appreciable loss of power, with consequent larger necessity for fuel to enable the engine to do the work.

Evidences of Power Loss.—Anyone can obtain sensible evidence of this loss by feeling the driving disk after it has been working some minutes, and noting that it is considerably heated because of this friction loss. It is also evident that, if the pressure is increased between the surfaces, the friction is also increased, and that a good driver should not set the disks together with more pressure than is actually needed to insure proper propulsion. This is true not only from the friction point of view but to prevent needless strains and distortion of the framing, bearings and other parts.

Suitable Friction Metals.—Since the driving ability depends upon the friction co-efficient, many experiments have been made to secure the best metals or materials for these disks and nearly every substance has been tried. Thus a steel driven disk running upon a copper driving disk has been used. Steel upon steel, with the driven disk quite thin, and therefore quite free from twisting and slipping friction, has been used, but this requires very high pressure. Cast iron for the driving disk and straw paper, or tarred paper, or leather, for the driven disk is a very common combination and quite a satisfactory one. Since aluminum has become common it is very frequently used to save weight. It has also a higher friction co-efficient than cast iron. This is stated variously, but usually at about 10%; that is to say, an aluminum driving disk will transmit 10% more power than a cast iron disk of the same size used at the same pressure.

Maintaining Friction Conditions.—It is quite evident that anything which destroys or lessens the friction co-efficient between surfaces is objectionable in this form of drive. On this account it must be kept free from oil, as a drop or two of excess oil often renders it inoperative. So also it must be free from frost or ice. Cases have occurred in which such a drive refused to work, even on a level floor, because the exhaust gases containing water vapor had reached the *driving disk and* been frozen on its surface, forming an

exceptionally slippery covering, over which the driven disk slipped without sufficient power to propel.

Friction Versus Pressure.—Increasing the pressure between the disks would only increase the pressure on the bearings, but not permit driving. The contrary condition is also true. Driven disks of leather, when exposed to the dust and dirt from the road, have become so filled with particles of gravel as to present a fairly solid stone surface, which would slip over the cast iron driving surface with practically less friction than the bearing friction, and with the result that driving ceased. Even paper driven disks, thoroughly dry and hard, because filled with road dust, have shown insufficient friction to drive, even on level road and with a light vehicle. To illustrate the need for care, in such an event as this dry disk surface mentioned, a single application of heavy cylinder oil, amounting to but a few drops, has rendered the surface sufficiently "tacky" to permit perfect driving and hill-climbing, even though the vehicle, before this application, had refused to drive even on the level.

Advantages of the Friction Drive.—Thus far the disadvantages of the friction system have been dwelt upon, because most experimenters have found these disadvantages and paid dearly for the information. As a matter of usage, this drive is a very sweet and satisfactory one. With it the engine may be run at its most economical or most powerful speed, and the speed of the vehicle may be varied to meet the road conditions. Thus, when approaching a hill, the gear ratio may be lowered, so that the vehicle moves more slowly, but with increased power, as the grade becomes steeper, and this without any loss of motion or idle strokes of the engine, such as commonly occur when one gear of the tooth variety is thrown out of engagement and another gear substituted.

Operating the Friction Drive.—With the friction drive the operator starts by making contact near the center of the driving disk, and, as the vehicle gathers speed and the engine seems more than able to propel it, the driven disk is shifted outward, constantly driving, but acquiring a higher rate of speed, which very quickly and sweetly brings the vehicle up to maximum. Particularly is this action sweet when towing another vehicle or doing unusual work. For example, the usual gear transmission is so arranged that the engine will accommodate itself to the differences in leverage or gear-ratio, between one speed and the next; but if we double the load, as in towing another vehicle of the same weight, the engine often will not accommodate itself to the wide jump between gears. Thus, if one starts a heavy load on the low gear, and then desires to take up the next speed, one throws out the low gear, but he may be unable to get the engine pulling on the next gear until the load has slowed down below the ability of the next speed to handle the load. This, of course, involves a second attempt on the

low and a further attempt at shifting to a higher gear. With the friction gear, no such intermission occurs, because the gear-ratio is shifted as the quality of the road, the size of the load, and the power and speed of the engine, permit.

Simplicity and Efficiency.—Since there are no gears of the tooth variety, and but few parts, in this form of friction transmission, it is very attractive and has sold readily when shown, as well as given good exhibitions of its ability in many ways. Friction driven cars commonly perform feats not possible with gear driven cars, because of this ability to favor the engine, and to permit it to work under its most advantageous conditions.

Limitations of Friction Drive.—In spite of these good points, however, most makers, who have tried, or who have marketed, friction gears, have abandoned them sooner or later. The fact may be safely accepted, therefore, that, while the friction gear is a sweet type and possesses many advantages, it is not best adapted to automobile work, and that its use very rightly should be limited to certain services where the duty is not severe. This is fairly well illustrated in machine shop practice, where friction devices are used for light service only. If the friction device has not found wide application in machine shop work, where conditions can be more carefully controlled than on the wet, muddy, icy and dirty roads, it is reasonably safe to assume that it will not find wide use in automobile work.

Variant Forms in Friction Drive.—Many modifications of the friction disk drive have been used, but while these have embodied some advantages, they have also involved some disadvantages, and, in general, have been abandoned, because of the same faults as have been described in connection with the usual form of disk friction. One common form uses the edge of the driving disk as the working surface, while the driven disk presents its face. This arrangement results in giving high speeds as the driving disk contact nears the center of the driven disk, and low speed when the contact is at the outside. It is best adapted to designs in which high speeds are seldom used, and in which heavy loads and low speeds are the normal practice. A modification of this arrangement uses two driven disks, between which the driving disk is placed, so that one is driven in one direction, the other in the opposite direction. One driven disk propels one wheel of the vehicle by sprocket and chain, while the other propels the other wheel through an intermediate gear, which reverses its motion. Thus this transmission drives both wheels of the vehicle in the same direction. A modification of this form has two driven disks and also two driving disks, which latter are mounted on a driving shaft having universal joints, so that one driving disk can be thrown against the driven disk at one side of the driven shaft axis, as the other is thrown against the opposite driven disk on

the opposite side of the driven axis. This arrangement drives both driven disks in the same direction. By straightening the driving shaft no disk is in contact, and no driving results. By throwing the driven shaft into an opposite angle or position, the disks contact on their opposite sides, and thus drive the driven disks in the opposite direction for reverse purposes. Faster speeds are secured by causing the driving disks to stand near the axis of the driven ones, while slower speeds result from having them farther apart.

Beveled Friction Disk Drive.—A still further modification, which is rather less complicated, makes use of two idle disks driven at their beveled edges by the beveled edge of the driving disk attached to the motor shaft. These beveled edges may be bevel-tooth gears if preferred. The driven disk moves between these idlers and is in contact with both of them when driving. When near to the center its speed is slow but powerful. As the driven disk is moved forward from the center or axis of the idlers, its speed increases, until it reaches their periphery, where it is greatest. At this point it is usually arranged to clutch into the driving disk, passing out of engagement with the idlers, thus driving at the engine high speed, but securing all the advantages of the friction drive at speeds lower than high speed. To reverse, the driven disk is carried to the rear of the idler axis, and thus drives in a reverse position. To release, the idlers are separated and disengage both the disks.

Combined Gear and Friction Drive.—There have been many combinations proposed, in which gears transmitted most of the power, but a friction disk arrangement of some sort varied the speed, thus giving a change-speed gear, combining the positiveness of the gear drive with the flexibility of the friction drive. Usually such a device has run into infinity at one end or the other of its range, and has been found to work badly in practice, because of this fact, although, theoretically, a superior design.

The Ratchet Drive.—Next to the friction-disk arrangement with its variable speed, inventors have probably worked most over forms of levers of various lengths, by which they hoped to secure variable speeds and powers at will. One of the best-known devices, which has been tried by a number of inventors, has a lever journaled on the driven axle, and provided with a ratchet and pawl, whereby an oscillating movement of the lever revolved the axle. This lever was connected to a crank on the engine shaft by a suitable connecting rod, and means for shifting the attachment of the rod to the lever along the lever length was provided. Thus, when the connecting rod pulled on the end of the lever, a very powerful drive resulted, but, since the movement of the connecting rod was fixed by the crank to which it was attached at its other end, it is quite evident that the speed of rotation of the driven shaft must be small.

Speed-Varying and Reverse.—Moving the lever end of the connecting rod toward the driven shaft shortened the lever, but kept the same length of movement, with consequent increased angular motion, and, therefore, increased rotative speed. This arrangement for speed-varying served its purpose perfectly, and no fault was to be found with this part of it. If the driven shaft was fitted with a ratchet wheel having suitable teeth and the pawl was made reversible, the device would drive in the reverse direction as perfectly as forward. Continuous application of power was sought for by increasing the number of cranks, connecting rods and levers, all operating on the same ratchet wheel and in some cases each crank operated two connecting rods and levers, one at each side of the ratchet wheel, so that one operated on the pulling stroke, the other on the pushing stroke of the crank. Perhaps the best example of this device was the so-called Universal truck, originated in Philadelphia, and shown at several successive automobile shows, as well as giving apparently good service throughout the year.

Defects of the Ratchet Drive.—This system, however, has one serious fault that does not appear to permit practical improvement. This is that the motion of the lever and the crank are never angularly constant. The crank accelerates the connecting rod up to mid-stroke, and then retards it to the end of the stroke. The vehicle is propelled by the lever from such a point in the crank stroke as corresponds with the engine and vehicle speed up to mid-stroke, after which, the vehicle, having attained this maximum motion, the retarding pull on the connecting rod simply fails to propel the vehicle during the second half of the stroke. Of course there is no propulsion on this particular lever on the return stroke, so that in a complete revolution of the engine shaft the pull on the connecting rod can take place only during one-fourth a revolution and does in fact take place during a very much shortened part of this one-fourth, owing to the speed of the vehicle. Thus, if the strokes come frequently and the speed of the vehicle is fairly constant, the power is applied only near mid-stroke of the connecting rod and up to the mid-stroke point.

Ratchet Drive Improvements.—Inserting a spring of some sort in the connecting rod may slightly increase the length of the working stroke, but it nearly always does so at some loss of power, because there is nothing gained if the spring is compressed on the accelerating portion of the working half-revolution, and then released on the retarding portion. The spring, to be of value, must be able to propel the vehicle and simply relieve the most rapid motion of the crank and connecting rod at mid-stroke; the spring having fully expanded before the retarding effect of the crank has become prominent. Further, since the device depends on a variable leverage, it is evident that the spring must also be variable in

strength, or else it does not work properly at various speeds. In short, the device drives by a series of short violent jerks, and the mechanism must be well-designed in order to stand up under such abuse.

Ratchet Drive and Fly-Wheel Weight.—Some designers have proposed using extremely light fly-wheels or none at all, or fly-wheels attached elastically, so that the piston action could expend itself directly on the lever. Such an arrangement permits the elasticity of the gases to assert themselves by a direct pull on the lever, and, if properly worked out, would probably permit the lever drive to be a practical one. But, thus far, no vehicle employing this device has attained any prominence on the market.

The Hydraulic Drive.—Directly in line with the friction-disk and variable-lever devices is the hydraulic transmission, which is extremely simple in theory, and has been worked out by a number of people in fairly practical form. The best-known form at present seems to be the Manly, adopted by one of the well-known makers of fire-fighting, self-propelled vehicles. The general thought in connection with such forms of drive is that the engine operates a pump, which sends oil, water, or other incompressible liquid, to a motor on the driven shaft, with suitable arrangements, whereby much liquid at low pressure, or a little liquid at high pressure, may act upon the motor, and thus propel the vehicle; either at high speed with little power, or low speed with great power.

Defects of Earlier Types.—The earlier experimenters along this line found much loss from leaks and internal friction, and generally abandoned the project. Others lost power because of the presence of gas or vapor, which gave elasticity, instead of positiveness, and interfered with the action of the pump or motor. Several methods of securing the desired results have been used, but, generally, such a device employs variable-stroke pumps and motors, so that, as the pump stroke is shortened, the quantity of liquid is less, but the pressure generated, if it meets resistance, may be very high. On the other hand, the motor may have its stroke lengthened, and thus move slowly, but powerfully, because of the double reason that it gets less working liquid and is able to accommodate more.

Uses of the Hydraulic Drive.—Whether the hydraulic drive will attain a large future or not is very problematical. Undoubtedly, it is more expensive than most forms of drives now used, and will undoubtedly never become popular on the popular-priced vehicles. For widely-varying service, however, particularly high quality service like fire-engine work, it seems admirably adapted. Probably for large trucks, which have a widely varying load, it may also prove superior. It is certainly an attractive device.

Duryea Roller Drive.—Another form of friction drive that admits of great simplicity and reliability of construction employs grooved instead of toothed gears. Although depending for their driving ability on their friction engagement, they are not called friction gears, the term "roller drive" being preferred, since they are in effect rollers with circumferential V-shaped grooves in their faces. These grooves, which can be made with almost any preferred angle of opening, are usually cut at about 40 degrees, which makes meshing easy, and prevents rapid wear. A variable speed, as in

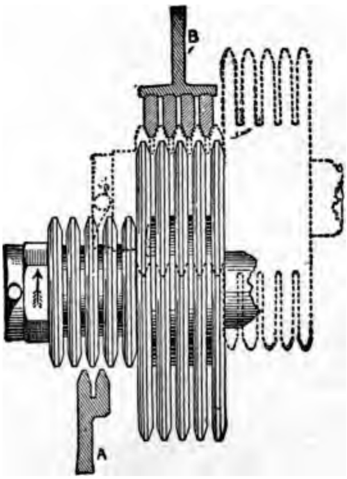

Fig. 27k.—Diagram of the construction and operation of the Duryea "frictionless" friction drive transmission. The two-diameter roller, carrying circumferential ridges, engages either of the two rings, A or B, which are hung on the road wheel concentric with its axle. The roller is on the engine shaft. In the diagram it is shown about to engage the high speed. The dotted lines show the position for low speed. For reverse, the roller engages the ring, A.

the usual friction drive, may not be obtained with such rollers, since it is necessary to vary by steps or sizes, as with a toothed gear drive. More specifically it consists of a large and a small driven ring carried by each rear wheel of the vehicle while the engine shaft, lying parallel to the rear axle and extending to these rings, carries two or more sizes of rollers on its ends. Suitable shifting mechanism enables the driver to shift these rollers laterally so as to bring any desired rollers into the plane of the rings and then to carry them forward into engagement with the large ring for forward movement or backward against the small ring for reverse movement. It will thus give two or more speeds forward and one or more backward without using gears.

chains, belts or housing. This drive works best in grit and dust and is the only drive that does not need protection. The great advantages to be had with this construction are (1) that, having no teeth, this drive is not noisy; (2) that it may be meshed at any time without the use of a clutch; and (3) that it will slip, when required, sufficiently to need no balance gear, or differential, in the rear axle or jack shaft. In short, this simple drive takes the place of clutch, transmission, propellor shaft, and differential and needs no complicated brakes and housing, because simple steel brake shoes bear on the larger grooved members and make a powerful brake. Such extreme simplicity is destined to come into very large use as the prices of automobiles are forced to lower levels, and more economic methods of construction must be found.

Driving Chains.—The early autos were very largely chain-driven, and this practice was partly copied from bicycle practice, and partly adopted because the chain offered flexibility, which the new vehicles seemed to require, and which other methods of driving had not met apparently, or which, at least, had not been developed to a practical point. The chain drive, in which a single chain extended from the engine shaft to the rear axle, was an early form, and so long as the engine was near the rear of the vehicle, this method served quite well. When, however, the engine was placed near the front as in the early Franklin cars, the chain became too long to give satisfaction. Its great length caused it to whip badly, with much strain on the bearings, and this amplitude of motion made it practically impossible to house it well. Also, a very little stretch or wear at each link, multiplied by the number of links, made the adjustment of the chain, to take up this wear, a very serious matter. For these reasons, cars having the engine in front almost universally adopted the shaft drive, as being much better adapted to cover the long distance between the front and rear axles.

Three-Chain Drive.—In some vehicles, where the chain-drive was retained, the use of three chains was found; a single chain connecting the engine at or near the front, with a jack shaft near the middle of the chassis, and from the ends of this to each of the rear wheels two other chains. This kept the length of any chain from being excessive, but it introduced more or less complication, in the matter of chain adjustment. For example, it is usually easy to move the engine or transmission forward, to take up the slack of the single chain, so the jack shaft is commonly moved backward, and to prevent additional slack in the rear chains, the rear axle must be moved correspondingly; while, to adjust the rear chains, it must be moved slightly farther. In the Holsman buggies short chains were used between the motor shaft and the swinging jack shaft, while ropes, or

chains encased in fabric, and finally bare chains themselves, were used from the jack shaft ends back to the grooves or sheaves on the rear wheels. This method of construction was applied to a number of vehicles, but has been very largely abandoned in favor of better methods. The progress in automobile development, therefore, has largely eliminated the former type of chain construction, and, except for the larger and heavier vehicles, the chain drive is not commonly seen.

Block Link Chains.—The chains originally used were of the block and side-link type. This pattern proved best adapted to light service in the bicycle business, and thus took precedence over other forms. But, when applied to automobiles, it was almost always used in sizes too small for the work, with the result that it acquired a bad reputation, from which it has not thus far recovered. Whether it will at some future time repeat the experience of the bicycle business, or whether the chain is thoroughly outclassed by other methods of power-transmission, cannot be stated at this time. The rapid growth of the business has created a large demand for chains, even though the proportion of vehicles using them has very largely diminished.

Roller Chains.—The more common and more lately accepted form of automobile chain is the roller type, consisting of side links held together by rivets, and these rivets encircled by a roller, which offered less friction, as the chain took its place upon the sprocket, than was often the case with the block of the block chain just described. The roller type had frequently been tried in bicycle and other service, but with no very large use. When the block chains in small sizes proved unsatisfactory in auto service, the roller chain, specially designed and applied for the work, was taken up and proved much better, with the result that the credit was given to this type, when much, if not all of it, should have been given to the size of the chain, or to the quality of material used.

Chain-Drive Efficiency.—One of the leading advantages of the chain, besides its flexibility, is its ability to transmit power with very little friction loss. Just how efficient the average chain is cannot be accurately determined, but it is believed that a single chain drive transmits the power from the motor to the rear axle with a loss of but five to fifteen per cent, depending upon the amount of power to be transmitted, the condition of the chain and sprockets, the quality of the bearings and similar features. Few drives can equal this, although the gear and worm drives now being employed, and most skillfully made, as well as carefully housed and lubricated, undoubtedly show similar efficiencies. It is readily apparent that these devices cannot work in the dirt and grit, as the earlier chains were expected to and actually did work. That they could give service, mile after mile,

under such conditions, is ample proof of the high quality of the chain, where flexibility is required, where a positive drive is necessary, and where the conditions are not the best.

Noise and Stretching of Chains.—One of the faults of the auto chain was its noise, rising largely from the fact that, as the chain stretched and the sprocket wore down in size, the two no longer fit together, and the chain began to rub upon and grind the teeth, or the working strain was taken by two or more teeth on opposite sides of the wheel, leaving the chain loose upon the intermediate portions, with consequent rattle of the loose part and grinding, where the strain was applied.

Chain Repairs and Adjustments.—This condition was not easily remedied. To discard the chain because it had stretched seemed an expensive proposition, but no adequate method of enlarging the sprocket was offered. Likewise, there was no method of shortening the chain, unless one chose to substitute new and shorter links instead of every second one stretched or elongated, as some users actually did. Part of this chain trouble and rapid deterioration arose from the fact that the maker had aimed to make his product 100% perfect, when he delivered it, and he, therefore, carefully fitted the sprocket and chain to one another, ignoring the fact that a few days' use would make the sprocket smaller and the chain longer.

Use of the Enlarged Sprocket.—A much better practice, followed by one or more makers, was to make the sprocket oversize, just as much as the chain would permit, with the result that the stretching of the chain and the wearing of the sprocket tended to bring the parts more nearly into their proper relation. The links, having become somewhat stretched before reaching their proper relative sizes, were more likely to continue in this practically perfect condition, and thus give the user a much more extended satisfaction. This ability to make the sprocket oversize was due to the fact that the chain links were usually somewhat longer than the teeth in their angular length, with the result that the teeth did not fully and completely fill the links. When applied to an oversize wheel, the rollers or blocks contacted with the non-working surface of each of the teeth at the leaving point, and, with the working surface, at the entering points of the wheel. Had the chain been a perfect fit, there would have been contacts with practically all the teeth on one side, leaving an opening near the opposite side of the teeth.

The "Silent" Gear Chain.—Recognizing these defects, chain makers cast about for a remedy, with the result that the "silent chain," first introduced by Renold of England, and afterward imitated by others, was put upon the market. This chain does not lie with its rivets, or blocks, between

the sprocket teeth, as in the more common form, but carries them rather above, or outside the teeth, and each link is provided with points at one or both ends, which act as teeth to engage the teeth of the sprocket. These points grip the sprocket teeth as they come in contact with it and, having gripped it, they hold the chain in that position, which insures perfect pitch line effect. Thus, as the link lies down into the space between the teeth, it comes in contact with the surface of the teeth, at a point high or low, that is to say, near or far from the center of the sprocket, according to the link length, the long link contacting with the sprocket tooth near its point, and, after contacting it, remains in position and serves to hold the chain rivet far out from the sprocket face. This outward position of the rivet causes the next link to fall slightly short of a maximum outward position, and thus the next link takes a more inward point of bearing, which supporting the rivet more nearly to the face of the sprocket, gives the next, or third, chain link opportunity to contact farther out toward the point of the third tooth, and so on. The result of this chain arrangement and action is that the chain selects its own pitch line on the sprocket, regardless of the amount of stretch of the chain or wear of the sprocket. That is to say, within reasonable limits, the worn and stretched chain simply works farther out on the teeth of the sprocket, which is equivalent to giving the sprocket a larger pitch diameter.

Uses of the "Silent Chain."—These silent chains have been made in rather more complicated and expensive forms than the common varieties, and, therefore, have not found so large a use as was formerly accorded to the roller type in automobile work, but the value of flexibility, of quiet running, and similar features, has forced the merits of this new form of drive upon the attention of designers, and recent years have shown a very wide application of the silent chain to many parts of the automobile, as for example, driving the cam shaft, the water pump, the magneto, or even in the transmission itself instead of gears. The ability of the chain to find its own pitch has alone made it less necessary to accurately locate the shafts, with respect to each other. The fact that the chain is almost, if not wholly, noiseless has made it much preferable to gears, particularly after it has given some service. The ability to place the shafts at any desired distance apart without necessarily changing the sprocket sizes, or introducing idlers between, has also been an argument in its favor.

CHAPTER XXVIII.

Motor Car Brakes.

Brake Requirements.—Next to the ability to go, the ability to stop is all important. Most of the early autos were sadly deficient in stopping ability. The designer seems to have devoted his attention wholly to parts that to him seemed more important, with the result that the brakes did not do their duty. Thus, if they held going forward, they would not hold backward. Or they burned out easily, and left the vehicle with no means of stopping. As a result of these shortcomings, buyers demanded emergency brakes. So, nowadays, most autos have two sets of brakes, in addition to the ability to stop by throttling the engine with the clutch and gears engaged, making really three methods each sufficient in itself. This is really a superfluity, and tends to over-confidence on the part of the user. Believing that he has two brakes he does not take the care of the one in daily use that he should. When the great need comes, the service brake is not able to respond, and the operator is either so rattled that he cannot think to use the emergency brake, or it is out of order. The result is an accident. One good brake, and that kept in order, is the safe plan, for, since this is constantly used for braking, the operator uses it instinctively in emergencies.

Care of Brakes.—The important thing is to keep the brake in order. See that the lever is properly adjusted, so that it has ample motion to fully apply the brake. See that the bands are neither soaked with oil, so as to be slippery, nor so dry that they are hard and do not grip. If too oily. apply common chalk. A bit of school crayon is handy for rubbing on the surface; or a thin knife can be used to scrape off some chalk dust and introduce it where needed. This both absorbs the oil and adds a slight grit to the surface. If too dry, a little belt dressing or heavy oil should be applied. Do not use rosin. This grips fiercely when cold, and makes the brake action too severe. When hot,

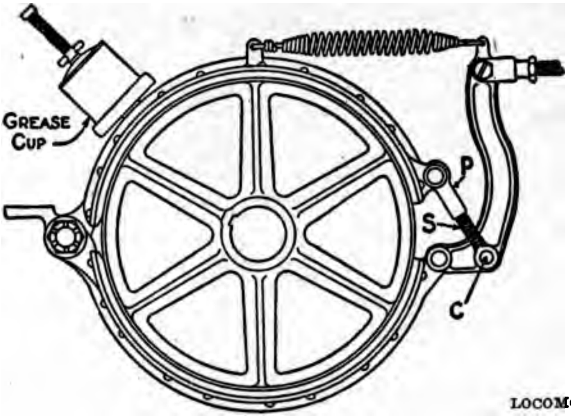

Fig. 28a.—Form of constricting or external band brake. The two semi-circular brake shoes or bands are pivoted at the left of the drum, as shown. They are normally held out of action by the spring, and are operated by the lever, through the toggle pivoted at C. P is a pivoted arm, into which works the adjusting screw, S, which determines the length of the arm, P, between pivots, and the action of the brake bands.

it becomes oily, and will not hold. Many brakes need no dressing. The material used and the leverage in operating affect this matter considerably.

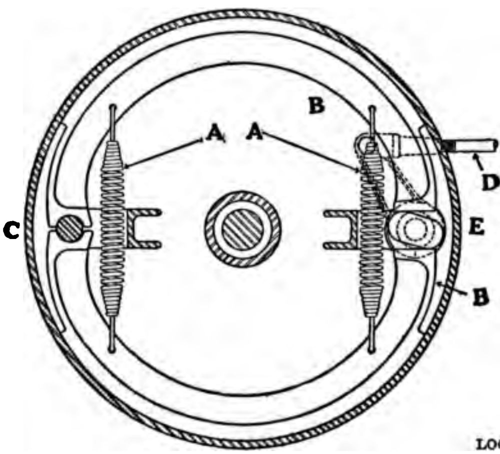

Fig. 28b.—Form of expanding ring, or internal brake. The two internal shoes or blocks, B, B, are normally held from contact with the internal drum, C, by the tension of springs, A, A. When the link, D, is moved to the right, the lever is actuated and cam, E, is turned so as to raise the ends of B and B, thus forcing these blocks into contact with the internal drum, C, and checking the revolution of the shaft or axle upon *which it turns.*

it becomes oily, and will not hold. Many brakes need no dressing. The material used and the leverage in operating affect this matter considerably.

"Dragging" in the Band Brake.—The band brake is the most common form, and is prone to spring out of shape enough to drag at some part of the circle. If the brake drum is hot after a run during which the brake has not been applied, it is pretty certain that the brake is dragging. Many an engine is blamed for not working well, when the brake is dragging, and making it work needlessly. The bands should hang free, all around. Do not assume that a little drag does not matter. If a piece of paper cannot be inserted all around, then it is certain that every little jolt will bring the band against the drum and make it drag. This drag may partly apply the brake. In any event the power it will take to overcome this dragging is quite out of proportion to the innocent looking small bit of the brake which touches. Many brakes are so closely enclosed that they cannot be gotten at, to see if they drag or not. In that event, feel the drum before and after a lively run, taking care not to use the brake during the run. If the drum warms up it is certain that the brake is dragging.

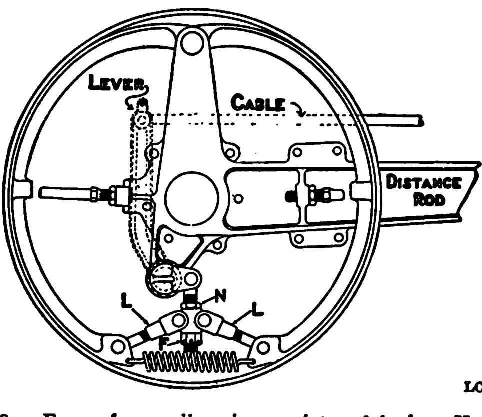

Fig. 28c.—Form of expanding ring, or internal brake. Here the two internal-acting blocks, normally held from contact by the spring, as shown, are forced into contact with the internal drum by the action of the toggles, when the lever is actuated by the cable. Adjustments may be made by the nuts, F and N, or by loosening the pins, L, L, from their pivots and lengthening or shortening the toggle arms by means of the screw adjustment, as indicated.

Shoe and Disk Brakes.—Shoe brakes are more accessible, and generally are arranged, so that it can be seen if the shoe drags or not. They are generally made with metal to *metal*, and there is very little to watch about them. Disk *brakes* are sometimes used. If run dry they separate nicely,

and run freely; also, if graphite is used between them. But, if run in oil, they are likely to have more or less drag, and this is objectionable. It is because of this fact that they are not much used.

Clutches and their Care.—Much that has been said in regard to the care of the brakes applies to the clutches. They should not drag when off, since this interferes with shifting the sliding gears or with starting the engine in the planetary and individual clutch types. They should not slip appreciably when set, since this heats them needlessly and wastes power. In fact, the slipping of a clutch can be considered a trouble of the same kind as the dragging of the brake band. It is constantly at work letting the ability of the engine go to waste. The paper test can be applied to the clutches to see if they are off all around. To note if they slip, watch whether the engine speeds up faster than does the vehicle when the throttle is opened in hill climbing. Slipping may be due to the surfaces being too dry and the leather needing a dressing of castor oil, but the most common complaint is " fierceness." A clutch should always take up its load easily. The chalk or fullers' earth dressing is recommended for this complaint. Care should be exercised not to get the earth in bearings where it will certainly do no good. The powder seems to make a sort of lubricant in that it prevents the surfaces from getting together at once. It seems to require some distance of rolling and sliding before it fully takes up the load, and often, in cases where it would seem that the chalk or earth would make a fierce clutch worse, it is found to be an assistance. If the clutch is quite powerful and able to carry the load, its " fierceness " may be cured by a dressing of graphite. This is a lubricant, but in many cases it makes a sweet acting and durable surfaced clutch. It will not burn, nor evaporate, and once right, the clutch is likely to remain so, with any of the powder dressings.

CHAPTER XXIX.

Motor Car Springs.

Spring Conditions.—Motor-vehicle springs have not been offered in a wide selection; partly because they have not yet been developed fully, and partly because, having heavy loads to carry, designers have preferred the better-known forms rather than experiment with newer designs. The more usual automobile spring is the semi-elliptic. Ordinarily such springs are placed lengthwise the vehicle, one at each corner of the chassis, resting upon the axle, or swung under it, as near to the wheel as possible. Several reasons exist for the adoption of the semi-elliptic spring. It supports the chassis frame at two places, and, therefore, tends to lessen the weight and increase the stiffness in this frame. Being attached more or less rigidly to the chassis frame, it resists sidewise motion, and thus insures the permanent alignment of the frame and wheels, which condition is favorable for the transmission of power by chains or similar means.

Full Elliptic Springs.—In the earlier cars the full elliptic spring was quite commonly used, but, for the reasons just stated, did not serve so well as the semi-elliptic, and was generally abandoned. Modern automobiles, however, seldom use chains, and the propellor shaft with universal joints does not require the maintenance of correct alignment, thus permitting a much wider choice of spring suspension.

Semi-Elliptic Springs.—Designers quite generally recognize the saving in axle weight and strength, if the springs are supported close to the wheels, and so the lighter, cheaper vehicles commonly use semi-elliptic springs, placed crosswise and supporting the body at their centers, while their ends are shackled to the axles or axle housings near the wheels and have some movement, which permits elongation of the spring under compression and some swaying movement of the vehicle body.

General Spring Qualities.—The number of leaves and the length of springs used show a wide variation. Many cars are equipped with short, stiff springs, having few leaves and little amplitude. Others have many leaves of thin steel, and are of considerable length, so as to secure easy riding and large spring amplitude. Thus, only a few years ago, 36-inch springs were in common use, while to-day 48-inch, 54-inch, and even longer, springs are not only common, but almost the rule. The resultant gain in comfort to the passengers, and to the life of the vehicle, is obvious. The full elliptic spring, so largely used on horse vehicles, is now quite common in motor vehicles, while modifications of these two forms are also found. Thus, instead of a horn, or spring iron, projecting from the corners of the frame, to carry the extreme ends of the semi-elliptic spring, an elastic support, forming a quarter-elliptic spring, is frequently used, the combination being known as the three-quarter elliptic.

General Spring Mounts.—Semi-elliptic springs on each side are sometimes combined with a third placed crosswise, making a three-quarter platform arrangement. The full platform spring, employing four semi-elliptics, is not usually found in automobile practice. In a few cars, semi-elliptics are used, the rear end being attached to the rear axle and two points of attachment for the middle and front end along the sides of the chassis. Such springs avoid projections to the rear of the axle, but, in order to support the load, must be considerably heavier than if attached at both ends to the frame, and carrying the load in the middle. This will readily be understood by considering the spring as a lever, having the weight of the vehicle at its ends, and double this weight in the center. In fact, such springs are termed cantilever springs and are winning much favor.

Coil Springs.—In connection with motor vehicles, coil springs have been largely employed, generally as supplementary to the short and stiff leaf spring of elliptic or semi-elliptic form. An advantage claimed, with apparently good reason, is that the vibration period of the coil spring differs from that of the leaf spring, and that one tends to damp out the vibrations of the other, so that each serves as a shock-absorber for the other. In fact, several well-known shock-absorbers take advantage of this principle, and find many satisfied users. A number of vehicles, like the Brush runabout, the Lansden electric vehicles, and the Duryea buggies, employ coil springs for supporting the load, and secure apparently good results from their use. The coil spring is usually a one-piece affair, whereas common elliptic springs are made up of a number of leaves. The difference between the two is that the leaf spring has considerable friction, which renders it slow and more or less stiff in action, with the result that it neither yields so freely, nor continues in motion after being disturbed. The coil spring yields instantly and readily to every shock, and

is, therefore, easy on both rider and mechanism, but it continues in vibration, after being disturbed, and is objected to by some on this account, unless provision is made for stopping these vibrations by some friction combination, as the use of leaf springs in the manner mentioned, or by shock absorbers, as used in the Brush.

Air-Cushion Springs.—Numerous attempts have been made at air springs, and there would seem to be no good reason why they should not be as successful and as superior for motor-vehicle work as air tires have proven to be. Many such devices have been shown, but for some reason they have not attained to much prominence. The Westinghouse is one of the later forms and has been developed through a series of experiments continued for many years. It consists, broadly, of a cylinder with piston in which the air is compressed, and with special means for holding the air, such as a liquid seal combined with steel springs, which normally carry a large part of the load and keep the air cushion extended. It is quite evident that, if the steel springs carry the empty vehicle body high, the air cushion will tend to fill with air rather than tend to force the air to escape, and that, therefore, the air will be in position to do its work when the vehicle is used and a load is carried.

Limitations of Some Air-Cushion Forms.—In some instances inflated air bags, generally more or less spherical in shape, have been used to carry the load, but these are open to the objection that, in time, they become leaky, and that the air gradually escapes. Further, like the coil steel spring, they are quite elastic, and, having no friction, rebound badly. The coil or single-leaf steel spring is objected to by some on this account, and the air-cushion is even more objectionable than the spring. The cost of this cushion is necessarily greater than the cost of a steel spring, while its supporting ability in directions other than vertical is not great. The usual springs have sufficient rigidity to hold the body of the car in place, above the axles of the vehicle, while allowing it a vertical motion. But a more or less inflated air-cushion is liable to be free in every direction, and permit the vehicle body to shift its position with respect to the wheels. This interferes with comfort in riding, also renders the vehicle likely to rub its mudguards against the wheels, or do itself similar damage. It is quite possible that a combination of air cushion with steel springs, or with piston and cylinder, may find a large market and secure results not obtained by the usual springs.

Forms of Steel Springs.—As the question of light weight becomes more fully recognized at its proper value, some substitute for the heavy leaf spring, now commonly used, will undoubtedly be sought for, and, along this line, substitutes are now occasionally seen. While motor-vehicle users have been offered almost every conceivable form

of spring, no particular design has attained the prominence that the leaf springs have secured, but in horse-vehicle service several modifications have found considerable use. One form is made of round steel bars having their ends bent at a right angle to the central portion, one of these ends being fastened to the body firmly and the point of the other pivoted or shackled to the vehicle axle. The central portion is thus twisted when weight is applied and this twist or torsion is resisted by the elasticity of the steel. This makes a very light, cheap, flexible and easy-riding spring, but also one which must be fitted to the vehicle with reasonable accuracy. Possibly this necessity for fitting these less-familiar varieties of springs is the main explanation why they are not more commonly used.

Advantages of Leaf Springs.—The leaf spring permits considerable overloading, because it is usually much stronger than the load requires, and an overload simply deflects it farther. With some forms, like the Z-shaped form mentioned, this overloading is liable to carry the spring beyond its elastic limit, and, therefore, is not permissible. The main difference between this form of spring and the common coil is that the coïl contains much more length of active material, and, therefore, is not likely to be overloaded, or, if overloaded, it simply closes, and permits the axle to take the strain, just as the leaf spring "bumps" when the load is too great for it to support. Many modifications of the Z-spring are found, some of them introducing a single coil into the center of the steel bar, which adds much to the life and elasticity, but which adds somewhat to the cost, because of the greater amount of material required.

One-Piece Springs.—One-piece springs, made by several makers, are of tapered steel, usually of the elliptic or semi-elliptic variety, and quite thick at the middle, but tapering toward the ends, this section of stock being such as to give proper strength at the middle and proper flexibility near the ends. To secure lighter weight, it is quite common to rib these single-leaf springs, and many of the multiple-leaf springs now used in automobile work are either ribbed or slightly curved in cross section, so as to stiffen them. In general, these springs are used under compression, but there are some exceptions, of which the practice of the Brush runabout makers is an example. They supported the upper end of a coil spring and hung the weight of the vehicle from the lower end, putting the spring under tension. The reason for this is not stated, but probably is that a hung body tends to come back to the same place, whereas, if a similar length of flexible spring were used, the spring might turn over to one side or the other and the body fail to stand in its proper place. A number of inventors have submitted spring hangings embodying a lever in con-

nection with the spring. Thus, if the short end of a lever extend between the body and the vehicle axle, a light spring attached to the long end of the lever will cause the short end to support the load. This light spring at the long end may be under tension or compression as may be preferred. The principal advantage of such an arrangement is that a fairly rigid mounting of the body may be obtained in a lateral direction, while giving fair motion vertically. There is some reason to believe that weight is saved because the lever used can be of considerable depth, and, therefore, not of great width, whereas a spring, to be sufficiently flexible, must be of considerable width, and not much depth. This saving of weight saves not only first cost, but, what is more important to the user, it saves weight of vehicle, which adds to the expense of operation, expense of maintenance, and total cost per mile.

Cantilever Springs.—While the spring which is carried by and pivoted on the mid-length of the vehicle body, with one end resting on or attached to the axle, has been known and used for many years, it did not come into general use until within about two years, and was made necessary by the combined demand for light weight and greater spring comfort. This spring is called "cantilever," to distinguish it from other forms like quarter-elliptic.

The pivot at its center permits both ends to flex, and thus it gives nearly double the spring movement to the axle that a quarter-elliptic would give, while being very little, if any, heavier. It is nearly twice as heavy as the semi-elliptic, which it resembles in shape, but gives nearly twice the movement. Most semi-elliptics fasten to the axles at their centers, or heavy parts, and thus add to the unsprung weight which must be carried by the tires. The cantilever type, like the cross-set semi-elliptic, has its center, or heavy portion, carried by the body, and only its light end supported by the axle, which saves tires, and contributes to easier body-action since the rebound of the body is largely due to the reaction of the spring, as it tries to force the wheels back to the ground after they have passed over an obstacle.

Upholstery Springs.—Closely related to the vehicle springs, and the elastic tires and wheels, are the springs of the upholstery. The maker of the horse vehicle aims to secure all his resiliency in the vehicle springs, but the motor-vehicle maker, driving over the same roads with a much faster carriage, is compelled to make much more elaborate preparation to overcome the shocks of the road. Consequently he not only uses pneumatic tires and very long and elastic springs, but he also employs exceedingly deep cushions and backs to the seats. Where three or four inches was once regarded as a sufficient depth of cushion, six, eight and ten are now common depths, and twelve and fourteen are occasionally found. Further, these depths are secured by superior steel springs, forming the base of the

cushions and backs, whereas in the cheaper horse venicles the springs are seldom of tempered steel, and are, therefore, not only less elastic, but also quite easily, take a permanent set, with the result that the cushions are quickly distorted, and not perfectly satisfactory. The deep trimmings require not only first-class springs, but first-class material at every point, because their great amplitude of action throws constant movement upon practically every part, and quickly wears out the upholstering, unless of the best quality.

Spring and Air Supports in Cushions.—One maker of cushion springs suits them to a variety of weights of passengers by employing two sets, one set being considerably taller than the other, so that, when the cushion is depressed by a heavy passenger, the second set of springs takes part of the load, and the cushion supports the passenger perfectly. More than one length of spring in a single cushion is now commonly used to secure greater height at the front of the cushion than at the rear, which is believed to add comfort to the vehicle, although at some slight additional cost. A further comfort is secured by making the cushions nearly air-tight, so that a sudden movement is resisted by the air contained within the cushion, much as would be the case if the cushion were air-tight. This slow escape and inflation by air prevents the cushion from bouncing, and makes a steady support much appreciated by the user.

Deep-Spring Back Cushions.—The same general thought of comfort for the rider is found also in back upholstering. A few years ago the curved shapes of the seats and tonneaus presented a problem that most trimmers did not attempt to solve, but simply dodged by making the trimming very shallow, and usually stuffed with hair or wadding, instead of being mounted upon springs. This was so common that few buyers recognized the value of the deep springs to be found in the product of a few makers, but to-day there is a general knowledge of the value, from the point of comfort, of deep springs in the backs of the seats. The proper back should be practically vertical, so that the rider may sit erect, when this position is preferred, and still derive considerable support from the back. When, however, one prefers to lean against the back, the deep springs should permit this, and allow him to sink into the upholstering comfortably, and to be gently but firmly supported therein.

Hammock Seats.—Whether, or not, this present form of upholstering will continue is a question. The growing demand for smaller and lighter vehicles may radically change present methods, and the hammock seat, as recently shown on a foreign vehicle, may find followers on this side of the water. (The hammock saddle for bicycles was the first great improvement in the modeın bicycle. It was followed by a host of saddles of various kinds.) It consists of a light frame, more or less elastic, forming the sides, or arms, and

back of the seat, and carrying simply a sheet of flexible fabric like strong canvas. This combined a seat and back that followed every movement of the passenger, while the supporting arms, more or less elastic, added much to security and comfort. That such a simple contrivance would be considered artistic is doubtless asking too much, but that it is in the line of light weight, simplicity, low cost and good service seems unquestionable.

The "Buckboard" Vehicle.—In general, the spring problem is covered by the construction of the tires, body springs and upholstering elasticity, but a number of inventors, knowing the easy riding-qualities of the Vermont buckboard, have attempted to embody its principle in the automobile. The Orient buckboard of some years past was one of these attempts, and was a very comfortable vehicle, when the small wheels, slight upholstering and similar objectionable features were considered. The failure of this vehicle to find popularity cannot, therefore, be considered an argument against the buckboard shape or principle. The makers of the Franklin car claim much gain in easy riding and long life, as well as in light weight, from their wooden frames. This frame is made of five or six pieces of wood, glued together to form a single bar, and these bars are used to form the complete frame. That wood will remain elastic, where steel is likely to fail, and that wood absorbs vibrations, rather than transmitting them, is very generally accepted. It is not possible to foresee the progress of the industry sufficiently well to determine whether the large, enclosed body will predominate—it would, of course, necessitate rigid construction—or whether light, simple frames will be finally accepted, and flexibility of frame be considered a valuable feature. The tendency to-day seems rather toward the former construction, although it is certain that the lighter vehicles are selling more rapidly than the heavier ones, and are steadily growing in favor.

Side-Spring Constructions.—A few of the earlier autos were fitted with side springs, that is to say, elastic members extending from the front to the rear axles, and carrying the body about midway their length. This form of spring is one of the most successful in rough-road countries, where great flexibility and spring elasticity are necessary. The extreme length of the motor vehicle, however, militated against the use of this type of spring, while the weight of the load, mounted upon it, required it to be so heavy that it was objectionable from this point of view. Whether the future will see some satisfactory substitute for the side spring is a question, but many experts believe that a system of levers, combined with springs, can be arranged to operate in this manner satisfactorily.

Cantilever and Coil Spring.—The weight of the springs is an appreciable factor in the total weight of a light car, and

designers have striven to secure easy riding without adding to the total weight. They recognize that a bar or lever, particularly a tubular one, is much lighter than a spring of leaves of same length, and, as mentioned before, they sometimes substitute such a bar with a light but efficient coil or torsion spring, instead of the more common leaf spring. In the Duryea light cars the rear axle is carried by tubular cantilevers or radius rods pivoted to the chassis, while about mid length of these levers are placed light springs which rest on the levers and carry the rear ends of the chassis frame. While coils were first used in this construction, torsion springs are winning preference, because they are even lighter than the coils, and permit a greater amplitude with less metal. Further, several torsion springs may be used, side by side, and one taken out, or another added, to suit the spring exactly to the load to be carried. Such an adjustment secures the most perfect spring action and a comfort not commonly regarded as possible.

Buffers and Shock-Absorbers.—The spring problem as applied to automobiles has been generally that of fitting a spring to each corner of a rectangular rigid frame, heavily weighted at both ends, and, therefore, not free to accommodate itself to the inequalities of the roads. This requirement has resulted in a quite rigid construction, and frequently forced the springs to bump against the axles, with the result that many vehicles are provided with rubber buffers, to soften the stroke of the spring against the axle. It also demanded the use of shock absorbers of various kinds, as well as of supplemental springs, either in the place of the rubber buffers, or to add strength or amplitude to the regular springs. In some vehicles the springs are doubled by having helper springs, which take up the load as the main springs reach their limit. With greater knowledge of the motor vehicle problems, designers will undoubtedly find some way to apply horse-vehicle experience in this matter. In the horse vehicle we find very often that the weight of the body and its load is concentrated at the center of the vehicle, and that this body is mounted upon springs, practically in a single line. When side springs are used, this line of mounting is across the vehicle, and under the main load.

Single-Line Spring Mounting.—When elliptic or semi-elliptic springs, in front and rear, are used, this mounting line is lengthwise the vehicle, and at its center. This latter arrangement is quite common in motor vehicles, and is possibly the best that can be devised with the elliptic or semi-elliptic spring, and, with the long bodies and present weight distributions now used. The advantage of this single-line mounting is that it permits the body to rock or roll, or, more correctly speaking, it permits two wheels to rise or drop, without greatly disturbing the body. It will readily be seen that the inertia of the mass of the body and its load will *hold the body* steadily, if the springs permit the wheels to

rise and fall over the obstacle. But, if these springs are placed well to the outside of the body, they have a great leverage, and the raising of a wheel, not only compresses the spring, but causes the spring to lift its part of the body, with consequent transmission of the shock from the wheel to the rider. If the supporting line is across the body of the vehicle, then both front wheels may rise over a water-break, a railroad track or street crossing without disturbing the balance of the body, but if the springs connect the forward axle with the front of the vehicle, they are more certain to transmit the lift of the axle to the body.

Weight-Distribution and Springs.—In connection with this last-mentioned action one must keep in mind the effect of having the weight at the ends, rather than at the center, which is one of the great differences between the horse vehicle and the motor vehicle. Everyone is familiar with the tight-rope-walker who uses a long pole, heavily weighted at the ends, to assist himself in maintaining his position upon the rope. The automobile body with the heavy engine at one end, and the heavy gasolene tank at the other, may well be compared to the rope-walker's pole. This heavy-ended pole, when in a given position, is not easily moved out of it, but, when started into motion, it is not easily brought to rest. As applied to the automobile, the consequence is that the front and rear springs are needlessly overworked, because the weight is so largely at the ends; first, in that they are compressed unduly, because the body will not move and permit the wheels to rise freely over the obstacle, and then they are again unduly extended, because the body, after moving, continues, and the springs must resist this motion. This is one of the reasons why the large cars, in particular, require shock-absorbers, or other means, to protect and assist the springs, and why motor vehicles have been proverbially hard riding, as compared with horse-drawn vehicles, although the latter have been equipped with solid tires only. In short, the theoretical mounting would group the weight at the mid-position of the wheels, where it would receive the least effect from any wheel, and would spring-mount in such manner that each wheel should be as free as possible to rise and fall, without forcibly transferring its motion to the body. That such motor vehicles can be built, and will be built, is certain.

Dimensions of Springs.—Possibly no part of the automobile is more widely varied than the springs, which are long or short, wide or narrow, stiff or limber, much according to the ideas of the designer, rather than according to any fixed practice or formula. In designing a vehicle, the maker draws largely upon his own experience and upon the needs of the locality with which he is best acquainted. The result is that in a good-roads country the makers are likely to use springs too short to be satisfactory on rough roads. Vice versa, a maker accustomed to rough roads will

most likely fit his vehicle with springs longer than commonly used in a good-roads territory. Considerable choice also exists in the thickness of the leaves forming the springs and their width, so that no commonly-accepted rule can be laid down in this matter. In fact, some half dozen factors enter into the problem of properly springing a vehicle, and, because most of these are variable, it is quite common to adopt springs by the rule of thumb, or by comparison with some known spring already in service in a similar vehicle, or by putting the matter up to the spring maker, and permitting his experience to indicate what length and size should be adopted.

Thickness of Springs.—The thickness of the material, of which the spring leaves are made, has much to do with the action of the spring, also the number of leaves required. It is quite evident that thick leaves are less flexible than thin ones, so a smaller number must be used. In some cases a single leaf is used, tapered, so as to be thick in the center and thin at the ends, as already explained. It is quite evident also, that a thin leaf will bend more times than a thick leaf, or bend farther, so that the thin-leaf spring either gives a longer life or else it gives better service, assuming that the material and other proportions to be the same.

Number of Spring Leaves.—Next to the thickness of the leaves is the number of the leaves, it being evident that any desired stiffness can be obtained if a sufficient number of leaves are used; thus a locomotive spring is a very heavy mass of fairly flexible leaves built one above the other, each leaf being slightly longer than the one underneath it. In order to get the best effect, not only are the leaves made longer, but it is very common to taper them in thickness for some distance so that no abrupt bending point exists. This is not essential in a spring constructed as the locomotive spring, and used where there is but little difference in length of the joining leaves, but it becomes quite essential in long and light springs such as are used on road vehicles, for if the leaves are not properly tapered, the bending action, as the spring operates, takes place largely at the points where one leaf stops and allows the succeeding leaves to carry the whole load. If, however, the points are tapered in thickness, they do not form an abrupt stop, but yield as the leaves above them yield, and so distribute the bending action along the entire mass of steel, with a closely even distribution. This insures long life and freedom from the excess strains, which are likely to bend or break the leaves.

Width of Steel Springs.—The width of the steel also affects the spring's capacity because, other dimensions being equal, a wide piece of steel is stiffer than a narrow one. Usually as the leaves are made thinner they are made wider to partly make up for loss of strength, which is otherwise made up by increasing the number of leaves.

Length of Steel Springs.—More than anything else, however, the supporting ability of a spring, and its value as a shock-absorbing device, depends upon its length, and this dimension is changed more often than other dimensions, in order to secure the desired spring amplitude, or load-carrying capacity. Thus, when autos were first made, it was quite common to see them fitted with springs of the usual carriage length of 30 to 36 inches, but both wider and thicker, so as to carry the additional load. Such stiff springs, however, had but little amplitude, and were not easy riding; so progress compelled the use of longer springs, and the short springs of ten years ago have practically ceased to be employed on modern automobiles.

The "Rise" of Steel Springs.—While the above are the more important factors entering into the spring problem, several other factors affect the matter, as, for example, the "rise" or opening of the spring. This is commonly measured from a line extending through the spring eyes down to the metal of the spring at its center, and has more or less effect upon the stiffness and sweetness of action of the spring. Generally, designers aim to so shape the springs that under their heaviest load, they practically straighten out, while, under light load, they are in a curved position. Since the load carried by the spring is commonly due to gravity, and is, therefore, directly downward, it is evident that a straight spring would offer less resistance to this load than a curved spring, which, under a downward thrust, would move less directly downward. On this account, the tendency of the much curved, or much bent spring, is to be stiffer than if it were more nearly straight. Consequently, the designer, seeking for amplitude with as little metal as possible, gets a rather increased action under heavy load, due to the fact that his spring has straightened out and becomes slightly longer as well as slightly more limber in proportion to its amount of deflection.

Friction in Leaf Springs.—Another matter which affects the spring action very perceptibly is the friction between the leaves. This has a good effect in that it damps out the vibrations, and acts as a shock-absorber. It also has a bad effect, in that it interferes with free spring action and thus, in effect, stiffens the spring. Experienced vehicle users generally keep their springs lubricated by graphite, held in place by some lubricant like vaseline or other suitable grease, or even by a light oil. The graphite, being hard, helps to hold the leaves apart and forms a smooth-sliding surface for them, while the oil or grease assists in retaining the graphite in place. The use of grease has the advantage that, once properly applied, it is not likely to work out and soil the paint, or collect dust, as does the lighter oil, which, when first applied, is liable to ooze out and make the vehicle look *unclean.* If the springs are kept lubricated the vehicle will *ride much* easier, than if they are permitted to operate with-

out lubrication, it being presumed, however, that the load is not more than the properly lubricated spring can carry, and that the free action of the spring is desired, rather than the dampened shock-absorber effect.

Grease Pockets.—The heavy weight of the motor vehicle and its load calls for longer and better springs than does the lighter weight of load and construction of the horse-drawn vehicle. Rather than make springs of unusual length to get the proper motion, designers have tried to increase the spring action. A very noticeable difference in softness and flexibility is found when the leaves are supplied with lubrication for their surfaces. This facilitates action, stops squeaks, and altho it doubtless shortens the life of the spring because of the increased movement of its fibers, is an advisable method. One concern sells very thin plates of perforated metal which are to be placed between the spring leaves and the perforations filled with grease. This insures perfect lubrication for a whole season and is a very efficient device. Another maker forms each spring leaf with a hollow in its concave of major surface near its ends where it does not interfere with the next or shorter leaf. This hollow is filled with grease when the spring is assembled and no further lubrication is needed for a long time.

Supplementary Spring Action.—A further influencing feature depends upon whether or not supplementary spring devices are used; thus the pneumatic-tired vehicle requires less perfect springing than one using large solid rubber tires, and still less than one using small rubber tires, or solid steel tires. Also, if rubber eyes are provided in the spring ends or supplementary springs, to permit some action at the spring ends, the leaves of the spring itself may be more rigid than would otherwise be permissible.

Spring Attachment.—Still another point affecting the spring strength is the matter of attachment. If the springs are carried at the center of the axle and support the center of the body at its end, they permit either wheel to rise more freely than if they are placed near the wheels, with the corner of the body supported directly above. This latter arrangement permits a rising wheel to lift that portion of the body quite powerfully, because of its leverage, and this the central attachment, just described, does not permit. The result is that a vehicle, sprung at its corners, is subjected to more strain and shock from road inequalities, than is one suspended at one or two middle line points, and in this connection, it may be noted that there is no great difference, whether the middle line of support of the body be lengthwise of the vehicle or crosswise. While, in general, these remarks refer to springs of the semi-elliptic, or full elliptic type, they quite generally apply to other shapes, such as the three-quarter platform spring, with the advantage that the platform type gets one central supporting point at any rate, and that

if its springs are long, and the other two points are well toward the center of the vehicle, it very largely overcomes the corner-lifting effect of the usual method of supporting.

Crosswise Mounted Springs.—The use of a single-leaf crosswise spring, carrying an end of the body at its center, but carried by the vehicle axle near its ends, secures, very largely, the freedom from lifting the body, as described above, while, at the same time, supporting the weight of the load upon the axle close to the wheels, and, therefore, with very little strain upon the center of the axle. This form of spring has found a very large usage, due to its simplicity, light weight and these other good qualities, but its length is again a matter of room between the wheels rather than of any fixed formula or rule of the maker. Given the length permissible, and a desire to get all the amplitude possible, the maker simply adopts the length, and then uses such thickness, width and number of leaves as seem best to meet his conditions.

Springs and Spring Steels.—These remarks, while applying to springs generally, have not taken into consideration the difference in steels. Some of the modern steels not only are much stiffer, when made into springs, than steels of poorer quality, but they have a much wider range of elasticity, that is to say they can be bent much farther before reaching their elastic limit, and on this account a much lighter spring may be used for a given load or a shorter spring for a given amplitude. The gain in this respect is from 30 to 50 per cent., according to the claims of spring-makers, which seem to be borne out by weights of springs submitted. The following formulæ may be of assistance to designers in choosing for their first vehicles.

Spring Formulæ.—The most accepted American formula for leaf springs to carry a certain load seems to be multiply the number (*n*) of leaves by their width (*w*) and this by the square of their thickness (*t*), and to divide this by six times the length (*l*) from the spring clip to the eye and multiply the quotient by the tension fiber stress (*s*) of the steel used. Thus: load $= \frac{nwt^2}{6l} \times s$. The figure for the fiber stress must be obtained from the steel maker or spring maker. It varies with the quality of the steel and with the treatment of it. In low-grade springs it may be figured as low as from 80,000 to 100,000 lbs., while in high-grade steels with heat treatment (three heats), it should run between 180,000 and 235,000 lbs. For coil springs the common formula seems to be that the load is two-tenths times the diameter (*d*) squared, divided by the mean radius (*r*), and multiplied by the tension fiber stress. Thus: load $= .2 \times \frac{d^2}{r} \times s$.

All lengths to be specified in inches.

Weight of Springs.—A matter of importance to the user is not only the amplitude of spring action, but also the weight of the spring, and he can, therefore, well afford to pay a slightly increased price to secure either a good quality of steel or a superior design of spring, in order to avoid needless weight in the vehicle. While the springs, resting upon the axle, do not add their weight to the vehicle so generally as does weight added to the body of the mechanism, still their own weight must be supported by themselves, and, in turn, by the axle, bearings, wheels and tires. These parts, therefore, must be slightly heavier, if the springs are heavier, and the total effect upon the tires is considerable. The heavy spring renders it more difficult to lift the wheel and axle, and thus there is more service upon the tire, with consequently much shorter life. On the other hand, the light weight spring does not offer resistance to raising the wheel and axle, and much increases the tire life, with consequent diminished expense for tires, not to mention the trouble which accompanies the wearing out of these important elements.

CHAPTER XXX.

MOTOR CAR WHEELS.

Requirements in Wheels.—No part of the auto is more essential than its wheels, because on their integrity depends the safety of the vehicle and its load, as well as the ability to travel. The auto industry was, at the start, unfortunate, in that it inherited from the bicycle certain constructive features totally unadapted to it. This may be understood from the fact that the bicycle is balanced over its track, and that, therefore, its wheels and frame are strained in a vertical plane only; whereas the motor vehicle, or any other vehicle making more than a single track, is not balanced, but maintains a practically constant relation to the surface over which it proceeds. Every inclination of such surface, also, of every change in direction, throws upon the wheels and framework strains altogether different from those imposed upon bicycle wheels. Designers should have recognized this difference, but, largely because bicycle wheels, rims, tires, ball-bearings, and similar parts, were available in the early days of automobile construction, auto manufacturers attempted to use them in the new vehicles. Very probably familiarity is another reason for this use, since many early auto makers had been engaged in the bicycle industry, just as several cycle makers had formerly been in the sewing machine business, but, whatever the reason for their adoption, the fact remains that cycle constructions were not suitable for automobile work.

Tire and Rim Conditions.—The tires, even though constructed for tandems, triplets or "quads," were far too light for the loads and strains placed upon them in auto service. The wheel rims of steel or wood, usually the former, were equally unsuited, while the slender wire spokes gave trouble continuously. In spite of these things, however, thousands of the spidery-looking little steamers, now recognized as toys pure and simple, were marketed, and really served to launch the auto industry as a full-fledged business.

Horse-Vehicle Precedents.—Here and there, however, were designers who had more consistent ideas, and held to standards that met the requirements of the new vehicle. Duryea, for example, although a pioneer rider and maker of bicycles, turned to the horse-vehicle industry for his automobile supplies, recognizing that the automobile is far more closely related to the horse vehicle, and subject to kindred uses, than is the bicycle or any other vehicle. He therefore used wooden wheels, steel tires and similar known and proven constructions, until experience and development offered something better. Only a short experience, however, was required to show that, while steel tires were possible, the mechanism, always destined to be more or less complicated, was largely saved from shock and damage by the interposition of a resilient tire. Consequently, as early as 1893 or 1894, he had abandoned solid steel tires, and was using cushion tires of rubber. The unusually heavy weight, coupled with the speed and peculiarities of the driving mechanism, subjected these tires to strains beyond those for which they had been constructed and forced him to look about for a still better article. This he found in the single-tube pneumatic tire, then being manufactured by the Hartford Rubber Company for heavy horse vehicles, such as small trucks. These tires were adopted early in 1895, and are believed to be the earliest pneumatic tires used on motor vehicles in the world.

Wheel Sizes on Motor Cars.—Wheels of the usual horse vehicle sizes were employed, running from 48 to 52 inches in diameter at the rear and 42 to 44 at the front, with spokes and hubs accordingly. As the vehicles were made more powerful and the loads became greater, slightly smaller wheels were employed such as 34 inches front and 38 inches rear; followed later by 30 inches front and 36 rear. These latter sizes have remained standard with Duryea vehicles since their adoption in 1897 and this long experience bears out the wisdom of the selection of these sizes. Other early experimenters followed a very similar course, although such pioneers as Haynes, Winton and Ford at first made use of steel wheels with wire spokes. Abroad, the practice was varied, but, in general, horse vehicle construction of wheels, rather than cycle construction, was followed, and the early Benz, Roger and similar autos were fitted with wooden wheels, and, usually, with tires of solid rubber.

The Origin of the Small Wheel.—The small wheel advent came with the introduction of the toy steamers, about 1899 and 1900, when vehicles using 28-inch wheels having 2-inch or 2½-inch tires were the most common. These were followed by the Olds, and several other small gasolene runabouts, using wheels of the same size. Generally used on good roads, these small sizes did not appear objectionable. They cost little, weighed little, and helped keep down the total weight of the vehicle, but they were wholly unsuited

for rough roads, did not ride easily, were extremely flimsy, and were a more or less constant source of trouble, and usually in need of repairs.

Reasons for Adopting Wooden Wheels.—The public, however, learns in time, and, having learned, is usually correct in its preferences; so, within a few years, the wire wheel was condemned, not because it could not be made satisfactorily, but because it had not been, and the wood wheel became the accepted form. In turning to the wood wheel, however, makers swung to the other extreme, and generally adopted the now universal artillery type. This wheel is applied for strength, rather than for lightness or cheapness, and was largely adopted because of its use abroad. Since the superior quality found in American hickory is not found in foreign woods, foreign wheel-makers were obliged to use larger and more expensive spokes than American wheelmakers, having high-grade hickory at their command.

Construction of the Artillery Wheel.—The artillery wheel, more specifically consists of a metal hub made in two parts and of a cluster of spokes of such dimension at the hub ends that they form a complete wooden center, from which and on each side of which the hub parts are placed and secured by bolting. If these spokes become loose the hub is easily separated so that repairs can be made or the bolts may be tightened, clamping the spokes more firmly and correcting the defect. In this form of wheel, used as early as 1894, and later, the two parts of the steel hub were riveted together, to insure greater safety than is possible with bolts. It was argued that repairs would be seldom needed, and that it is better to cut and replace rivets, than to be annoyed by loosened bolts, which are not only more expensive, but also heavier and less sightly than rivets.

Objections to the Artillery Wheel.—From the buyer's standpoint the artillery wheel is objectionable, principally because of its needless weight, although, being more costly, it indirectly affects the cost of the vehicle, for which he must pay when purchasing. From the maker's point of view, the artillery spokes require a large inner end, and, further, must be sawed from a much larger slab of wood than the more common form of spoke, as found in horse-drawn vehicle hubs. This latter spoke is not greatly larger at one end than at the other and very little material is wasted in its construction, yet by proper hub flanges, as in the Sarven wheels, its strength is little, if any, less than the strength of the artillery construction. The weight, however, of the Sarven and similar wheels is decidedly smaller, which makes the vehicle easier and more economical to propel, delays the destruction of the tires, and is generally much preferable.

Prospects for Lighter Constructions.—The time is not far distant when the buying public will demand the lighter,

more economical, and better construction, instead of the heavy, costly and clumsy artillery wheel. That there is any gain in strength, in the latter over the lighter and cheaper type, is easily disproved, when one notices the many horse-drawn vehicles of all sizes carrying loads of all weights, over all kinds of roads, with reasonable certainty of long life and satisfactory service. Wheels of the common type frequently give daily service, under business vehicles, for ten to twenty years, and certainly no complaints can be properly raised against such construction.

Steel-Hub Wheels.—The buyer who prefers all-steel hubs can secure them in the one-piece design practically as readily as in the artillery type, such hubs being cored to receive the spokes, which are driven into place just as they are more commonly driven into the wooden hubs generally used. A belief is sometimes expressed that wooden spokes will not remain tight in one-piece steel hubs for a long period, but the use of such wheels under fire engines, on the one hand, or farm wagons and implements, on the other, demonstrates the fallacy of this belief. A properly fitted spoke, properly seasoned before driving, and, then, properly primed with linseed oil, is practically weather-proof, and can be depended upon for years of service. But if an adjustable hub is preferred, this also can be provided, with which the spokes can be clamped more tightly, should occasion require. Such hubs, however, being made in two pieces, with spoke pockets or mortises open on one side, are slightly more expensive than the one-piece variety.

Steel Versus Wooden Hubs.—The usual wooden hub found on horse vehicles is commonly believed to hold the spokes better than metal hubs, although little or no ground exists for this belief. Possibly because of the slight elasticity of the wood forming the hub, the spoke may be driven into the hub more tightly in the first instance. Possibly also, the priming with oil swells both the spoke and the hub, and thus insures a more complete grip of the spoke in its mortise, than is afforded by the steel hub. Thus, some reason for this largely prevalent belief in the superiority of the wood hub may be found to exist.

Construction of Wooden Hubs.—Wooden hubs are seldom, or never, made without iron reinforcements, which bands or reinforcements add much strength and prevent danger of splitting, so that the size of the hub may be decidedly less than would be possible without these strengthening bands. These bands are always placed at the inner and outer ends (the butt and point of the hub), but in the Sarven wheel a malleable iron shell forms, not only the band but encloses the whole end of the hub, and forms a flange for the spokes.

The Sarven Wheel and Hub.—In the Sarven wheels *sixteen spokes* are commonly used, which number fills the hub

circle, just as the lesser number, used in the artillery wheel, fills the hub circle, by reason of their enlarged ends. The difference is that, in the artillery wheel, larger and fewer spokes are used, whereas in the Sarven smaller and more numerous spokes fill the hub. The great difference, and one of decided interest to the user, is the fact that the smaller spokes are more elastic, and, not only contribute to easy riding, but save the axles and other portions of the vehicle, thus adding to the life of the structure, and saving repairs. This resilience of the American light wheel with its hickory spokes is not appreciated by foreign wheel-makers who do not have such superior woods, nor is it appreciated by buyers of American autos, as will be shown below in connection with modern wire wheel construction.

Other Steel-Hub Wheels.—In the Warner wheel, hub bands are used, but the hub is encircled at its largest diameter by a malleable iron ring, through which the spokes pass, and by which they are supported for some distance above the usual wood hub diameter. In the Rouse wheel, a somewhat similar construction is used, except that the ring of the Warner is combined with the enclosing shell of the Sarven. The two last-named forms differ from the Sarven in that twelve or fourteen spokes are commonly found and metal fills the space between the spokes at the hub circle, instead of the spokes themselves forming a complete center to the full diameter of the metal rings or flanges. In these wheels of horse-vehicle construction, not only are the spokes elastic across the plane of the wheel, but the felly is also of wood, and more or less resilient. These fellies are usually tired by thin bands of steel, which do not seriously interfere with their elasticity.

Wheel Sizes and Elasticity.—In modern automobile construction the wheel sizes are so small that much elasticity across the plane of the wheel, or in any other direction, cannot be secured from the wooden spokes, and this fact is a strong argument against modern wheel sizes. That both makers and users are appreciating the value of larger wheels is shown by the steady movement toward their adoption. Where ten or a dozen years ago the small wheel was the accepted form, and was seldom found above 28 inches diameter, today all cars pretending to high grade use 36 inch or larger, and the average size is probably above 34, with a still continuing upward tendency. These sizes do not include solid-tired vehicles, like motor buggies, which employ wheels up to 44 inches, and, sometimes, 48 inches diameter, nor do they have reference to trucks, on which wheels of larger size are now commonly found.

Demountable Rims and Inelasticity.—The usual automobile wheel is fitted with a needlessly broad and heavy felly, on which is mounted a heavy channel or rim, for receiving the pneumatic tire. For quick repair purposes these rims are usually of the quick detachable or the demountable

type. In the quick detachable type only a portion of the rim is removable to permit quickly removing the tire, and this is both simpler and lighter than the demountable type, which is arranged to remove complete with the tire, the latter remaining inflated, if preferred. In either case these channels add much weight and rigidity to the circumference of the wheel, and, coupled with the large-section tires and small-diameter wheels, make the spoked portion of the wheel very small indeed. The result of this combination is a wheel devoid of elasticity or easy riding qualities, other than those imparted to it by its tire. On this account, solid tires have not found favor on motor vehicles, except in the few instances in which wheels of the horse-vehicle sizes are employed.

Demountable Wire Wheels.—Recognizing this condition, scientific men, principally abroad, have been experimenting with steel wheels, and have advocated demountable wheels, instead of demountable rims and tires. The advantage of the demountable wheel is that the tire channel can be of steel, without any wooden felly, and, therefore, nearly as flexible and elastic as the wooden felly, and steel band tire of the horse vehicle. Further, the steel wheel, unlike the wooden wheel, is a suspension affair, in which all spokes are under tension and tend to pull the rim toward the hub instead of being compression members as are the spokes of the wooden wheel, each member holding the felly away from the hub. Being tension members, the rim at any point is free to yield toward the hub, which yielding simply loosens the spokes at that point, but throws a slightly added tension on all the remaining spokes in the wheel. This fact adds much to the resiliency of the wheel, and thus sustains the tire in the performance of its duty as a road smoother.

Heating of the Tires in Operation.—The bending of the rubber and fabric forming the tire heats the tire, because of the friction at the bend, and this heating of the rubber softens and weakens it, with more or less rapid destruction of the tire by the road if the vehicle speed is high. This heating effect can easily be tested by sensitive fingers in bending a piece of tire, or, better still, a small piece of iron wire or sheet iron, which will become quite hot, when bent rapidly a number of times by one's fingers. The common rim and felly construction does not offer opportunity for the escape of this heat through the rim, because the wood is an excellent insulator, and bears tightly against the rim on its inner side; but, in the steel wheel construction, the rim is not only thin and readily passed through by the heat, but it is entered by many spokes, which serve as heat conductors and radiating devices, which carry the heat from the warm tire and rim out into the atmosphere through which the wheel is moving.

Steel Wheel Advantages.—Because of this resiliency and this ability to cool, the steel wheel has been found by experience to be much more economical of tires than the more common constructions, but part of this economy is doubtless due, also, to the lighter weight of the wheel, because a lighter channel can be used on a demountable wheel than is used on the usual wheel having demountable rims. This economy of tires is, therefore, undoubtedly another strong argument in favor of light weight.

Early Wire Wheels.—The early wire wheels were simple copies of the wheels used on the bicycles, particularly those for three and four riders, and were not designed for the side strains, contacts with curbs and many similar abuses, to which a vehicle wheel is subjected, but which are not given to a cycle wheel. The light-weight rims easily dented or buckled, the light spokes stretched, broke, rattled, and, otherwise, gave trouble, and the small and narrow hubs did not properly transmit the power, nor resist the strains.

Improved Wire Wheels.—The modern wire wheel, as now being offered on many European cars, and on some American ones, is a growth that has resulted from the cost of wood wheels, combined with their rigidity and weight, and these wire wheels represent good engineering practice. They have a very wide hub, projecting well beyond the plane of the wheel so that the ability of the wheel to resist sidewise strains, particularly from the outside, is excellent. Automobile wheels are seldom subjected to such strains from the inside, and so do not need such strength in the opposite direction. They are quite commonly constructed with two lines of spokes at or near the inner end, radiating from a quite large hub, and with a single series of spokes from the outer end, where the hub is much smaller. This arrangement causes the inner, shorter and more direct-acting spokes to do the driving, and support most of the weight, while the outer spokes are more suited to resist lateral distortion of the wheel than for the other purposes.

Probable Prospects of Steel Wheels.—That the steel wheel will win favor seems quite likely, although, so long as good wood can be obtained, the hickory wheel of long-proven correctness will find advocates. If wheel sizes continue to increase in favor with the public the steel wheel will not so readily grow in favor, but with better roads becoming more common each year, and with lighter weights and lower costs being demanded by the buying public, the prospects for a revival of the steel wheel of small diameter seem excellent.

Wheel Sizes and Road Surfaces.—The question of wheel size has been much debated by road users since the advent of the bicycle, which was later followed by the bicycle sulky and bike buggy, and later still, by the automobile,

first with bicycle-sized wheels, then, with much larger wheels, and still greater tires. A short review of the vehicle industry shows that wheels of five, six and even seven feet diameter were used on carriages in former years, and that these wheels were considered valuable, because of the extreme roughness and vileness of the roads. As roads, in general, have improved, wheel sizes became smaller, until, for many years past, horse vehicles have used wheels in sizes from three to four and one-half feet in diameter. More than a million family buggies, of two and four-passenger capacity, are sold every year in America, and American roads are largely made and repaired with these wheel sizes in consideration. That is to say, when the roads become objectionably bad for these wheel sizes, they are likely to be repaired and made passable for them. Such roads, however, are not well adapted to roller skates, or bicycles, or small-wheeled vehicles of any kind.

Results of Road Improvement.—Since the advent of the bicycle, there has been much agitation and educational effort on the subject of better roads; with the result that, probably, between eight and ten per cent of the American roads now pass as "improved." Since these, generally, are the most-used roads, the percentage of miles travelled annually shows much more favorable averages. It is likely that the improved roads are used three to five times as much as the non-improved roads; so that, of the total road length travelled, probably 20% to 25% is over improved roads, although not all of them are good, nor even adapted to exceedingly small wheels. The experience of makers and users of automobiles during the last dozen years has shown the advantage of large wheels over small ones, with the result that the standard 28-inch wheel of 1900 to 1902 has given way to 36-inch, or more, on practically all high-grade autos in 1915.

The Trend Toward Larger Wheels.—While most of the lower-priced cars are still fitted with small wheels for the sake of cheapness, it seems evident that these must follow the leadership of the better-grade goods, and, sooner or later, equip with larger wheels, possibly not larger than 34-inch but probably considerably larger. If horse vehicles running at slow speeds find wheels of 42 to 48 or 52 inches best for their purpose, it seems reasonable that motor vehicles carrying heavier loads, and travelling at higher speeds, should find need for wheels substantially as large, even though equipped with road-smoothing pneumatic tires, and this view is ably seconded by the fact that many street cars, and practically all railway cars, are equipped with 36-inch wheels, although running on the most perfect tracks that modern engineers know how to build.

Data on Wheel Sizes.—Users who have experimented with *various sizes* of wheels, under vehicles of identical construc-

tion, are unanimous in the opinion that the larger wheel rides more comfortably, and some say that each inch additional in wheel diameter is practically as valuable as a half-inch of pneumatic tire. The Agricultural College of Missouri some years ago made experiments to determine the most practical wheel sizes and from their report we quote the following principles, which have a direct bearing on the general situation affecting the wheels of motor cars:

"1. For the same loads, wagons with wheels of standard height (front 44 in., rear 55 in.) drew lighter than those with lower wheels.

"2. The difference in favor of the standard wheels was greater on road surfaces in bad condition than on good road surfaces.

"3. Low wheels cut deeper ruts than those of standard height.

* * * * *

"8. Diminishing the height of wheels below 30 inches front and 40 inches rear, increased the draft in greater proportion than it gained in convenience.

"9. On good roads, increasing the length of the rear axle so that the front and rear wheels will run in different tracks to avoid cutting ruts, did not increase the draft."

The same authority also figures the advantage of high on a macadam street (44 in. front, 55 in. rear) over medium (36 in. front, 40 in. rear) wheels at .7 pound, or .65 per cent; of medium over low (24 in. front, 28 in. rear) wheels at 8.7 pounds, or 8 per cent; of high over low wheels at 9.4 pounds, or 8.7 per cent for a load of 2,000 pounds. The following remark is added:

"At this rate the draft required to draw 2,000 pounds on the low wheels would draw 2,160 pounds on the medium wheels or 2,174 on the high ones; and the draft required to draw 2,000 on the medium wheels would draw 2,013 pounds on the high ones."

Similarly, tests made on dirt roads showed that "the high wheels drew 8.0 per cent lighter than the medium ones, and 12.6 per cent lighter than the low ones; the medium wheels drew 4.0 per cent lighter than the low ones."

General Rules for Wheel Sizes.—From the above-quoted data the following rules are adduced:

"1st. The power required to overcome axle friction diminishes as the diameter of the wheel increases, the diameter of the axle remaining the same; or, the power required to overcome axle friction increases as the diameter of the axle increases or the diameter of the wheel decreases.

"2d. The power required to draw a high wheel over an obstruction is less than that required for a low wheel bearing the same weight. (This is demonstrated by the usual formula for power in such cases, which makes it equivalent to the total weight (W) multiplied by the square root of *the product* of the height of the obstruction by the diameter *(2R) of the* wheel less the height of the obstruction, divided

by the length of the radius (R) of the wheel less the height of the obstruction. Since, as will be found, the figures for the expression, diameter minus height of obstruction divided by radius minus height of obstruction, decrease as the wheel diameter increases, the proportionately smaller power for large wheels may be understood.)

"3d. The resistance to penetration offered by sand, gravel, loose earth or mud, is greater for small wheels." (Such increase of resistance may be understood from the fact that, the smaller the wheel, the deeper it will penetrate into the soft road surface under the same weight.)

To epitomize the mathematical operations required to demonstrate the last proposition, it may be said that, as would be clear on reflection, that a given total weight tends to sink certain definite depth in a given quality of material (sand, mud, ashes, etc.) on the road surface. If such a given weight is on wheel supports, the depth to which each such support will sink will be in proportion to the length of a line drawn on the road surface between points on the circumference of each wheel immediately above the surface. Such line is the chord of an arc, or line separating a part of a circle from the total circumference. But, as reflection will show, such line, or chord, will subtend, or divide off, a smaller arc or portion of the circle in a large wheel than in a small one. Thus, a large wheel will penetrate less deeply into the sand or mud of the road, and will require less power to move the load through such road surfacing. Thus, to illustrate by an extreme case, suppose that a wheel of 1 foot diameter sinks half way into a certain road surface, so that the chord is the diameter of 1 foot subtending an arc of 180°, or one-half the circumference; a wheel of 2 feet diameter, of the same tread breadth, etc., carrying the same total load, should sink only to a depth of ⅙ circumference, since, on its circle a chord of one foot length subtends an arc of about 60°.

Automobile Spring Wheels.—Few problems have been given more thought by the inventive talent of the world than spring wheels. As a general fact, it is recognized that the proper place to absorb the vibration is at the obstacle causing it, and on this account the pneumatic tire is a perfect vibration-absorber, so long as the obstacles are small ones, and within its range of amplitude. The aim of inventors, more or less misguided, is to provide a substitute for the pneumatic tire that shall be more free from objections as well as of lower cost. These attempts, while particularly directed against the use of the pneumatic tire, are not new nor confined to a period since the introduction of the pneumatic tire, but go back many years previous. One and all, with practically no exceptions, have proven failures, and have sooner or later disappeared from the market without profit to their makers. While several reasons exist for this failure, the usual spring-wheel inventor fails to see the

more prominent ones, which will be stated here as fully as seems necessary.

Air Versus Metal Springs.—One fault is that nothing is so cheap, so light and so elastic as air. Gases form practically perfect springs, with very slight internal friction, so that they may be compressed and expanded to the small amount needed in a vehicle tire with very little loss of energy. Not so with steel, rubber or other spring materials. The variations in temperature of a rubber band, when stretched and released, are quite perceptible to the touch. A steel spring rapidly moved for a few times grows warm, because of the internal friction, and one may burn one's fingers uncomfortably in attempting to break a piece of small iron wire by bending it back and forth rapidly. Because of this perfect action of air, or other gases, and this friction-causing, power-losing behavior of metals, there is a considerable difference in efficiency between the two, which the inventor of the spring wheel cannot hope to compensate.

The Weight of Spring Wheels.—The matter of weight is probably of greater moment. The air in a pneumatic tire weighs but little, while the tire itself probably weighs less than the steel shoes or links to which the springs of a spring wheel are usually attached. Light weight is rapidly gaining recognition as a valuable feature, and spring wheels will stand little chance of finding favor on this account.

Spring Action in Spring Wheels.—The greatest objection to the spring wheel lies in the fact that the action of springs in a wheel is entirely different from that of the springs under the body of the vehicle, and must be either much more elastic or much shorter in life. It will readily be seen that the vehicle spring is under the compression of the load at all times, and, having been compressed until it properly supports that load, it is not called upon to make further movement unless some obstacle in the road brings it into action. Then the spring is compressed or released for a few vibrations, and is again quiescent until the next obstacle. Not so with the springs in the wheel. If placed at the rim, and strong enough to practically support the load, they are usually made so as to yield somewhat under the weight of the load, and thus are compressed and released at each turn of the wheel. If confined by a band, so as to be under a compression practically sufficient to carry the load without compression, they must be considerably heavier, and the restraining band must be heavy also. If so compressed, they yield only to small obstacles, but on striking a large obstacle they become so stiff under further compression as to be of little value as shock-absorbers. In this respect, they differ widely from the usual pneumatic tire.

The Action of the Pneumatic Tire.—To more fully understand this difference, consider the usual pneumatic tire and its action, as compared with one composed of small cylinders filled with air under pressure, and thus acting substantially as does the steel spring substituted. When the usual tire is compressed by the wheel running over an obstacle, the air is forced aside and expends its pressure by slightly increasing the pressure throughout the whole, but this same obstacle, if striking a cylinder containing air, would compress this until the air in the cylinder contained a very high pressure, which would limit further movement of the cylinder. In short, to secure equal tire action, much greater length would be required in the compressed air cylinders of our supposed tire than is required in the depth or diameter of the usual pneumatic tire; and since no metal spring is as good as an air or gas spring, it follows that still longer springs must be used if anything like the pneumatic tire effect is to be secured.

Wear on the Springs.—Generally, however, the steel spring is so arranged, either in the spokes or the hub, that it may be compressed when at the bottom and expanded when at the top. It will readily be seen that this gives a double or alternating movement at each turn of the wheel and very rapidly wears out and destroys any spring construction proposed. Further, it is evident that spring spokes as usually made must carry the whole weight of the vehicle on a very limited number of spokes, so that two or three, or, at most, half a dozen, spokes must be as strong and as able to resist the load as the corresponding spring of the vehicle. From this comparison it will be seen that any spring-spoked wheel, offering an appreciable resilience and amplitude, must be many times heavier than the spring of the vehicle usually employed near such wheel. Much the same thought applies to the various spring hubs, also to the pneumatic rings fitted near the hubs of the wheels for cushioning purposes. They are constantly in movement, being compressed on one side and expanded on the other, with vertical displacement on the fore and aft sides, all of which tends to quickly deteriorate them. This same vertical displacement occurs in practically every form of spring wheel, and does much to shorten its life. While each specific instance of this form of device has its peculiar faults, these above reasons indicate that no hope can be held for success from devices of the spring-wheel, spring-hub or spring-spoke types.

The Rubber Tire Situation.—The pneumatic tire is probably the most efficient shock-absorber possible to design, and is capable, undoubtedly, of further simplification, whenever the buying public is ready to accept simpler forms. Next to this, tires of solid rubber of proper consistency are most satisfactory, and while a variety of forms have been offered, the simpler forms are probably best. Many users,

however, believe that solid steel tires are ample and sufficient for motor vehicle work, and their use is all but universal on business vehicles in foreign cities, like Paris. Certain it is that smooth streets, such as asphalt pavement, permit the use of hard tires perfectly, and with little gain to be noticed from the substitution of either solid or pneumatic rubber tires.

The Perfect Wheel Inflexible.—It is quite evident that, on a perfect track, the perfect wheel should be one which maintains its circular form instead of flattening as does the usual rubber or air tire. The reason for this is that it takes power to flatten the tire, and that not all of this power is given back to the wheel, as the tire resumes its original shape. A lively pneumatic tire gives back most of this power, but loses some in friction, heating the rubber, and some in useless movement of the rubber, which is checked by the strength of the fabric, as the tire resumes its normal shape. This loss becomes considerable as speeds increase, and it is possible to imagine speeds sufficiently high to roll the wheel faster than the tire can return to its shape, so that no forward thrust is given by the kick of the tire behind the point of heaviest contact. In this event all of the power used to compress the tire ahead of the center of contact would be lost, just as though the tire was made of putty, which requires power to flatten it but which has no resiliency, to cause it to resume its shape, after being flattened out.

Tire and Spring Efficiency.—The solid steel tire does not flatten in front of the contact point and so loses no power from this cause. The solid rubber tire may be less economic or more so than the pneumatic, depending upon the nature of the road and the weight to be carried, as well as upon the speed of the vehicle. The spring wheel, or spring tire, is open to all these above-stated objections more fully than either the rubber or pneumatic tires, and would not have been given place in these pages, were it not for the fact that a sort of belief in it exists among the public generally.

CHAPTER XXXI.

Lubrication and Lubricants.

The Importance of Lubrication.—In the care of a car there is no single item so important as proper lubrication. It is the surfaces of moving parts that wear, and the life of a car will depend upon three things: (a) material; (b) proper driving, and (c) lubrication. Without due attention to the latter item, the best material and most careful driving will count for naught. But, no amount of pains in seeing that the parts are lubricated will probably care for the car, unless a thoroughly efficient and durable lubricant is selected.

Good Oils Essential.—This last thought must not be lost. To many people anything that looks like oil is oil, and good enough to serve, but such is far from the truth. There is naturally a constant temptation to save a little money by buying the low-priced "just-as-good" oils, but it is false economy in a heat engine. The dealer can make more profit on a cheap oil, sold at a high price, than he can on an expensive oil sold at the same price, but the dealer's profit is his own affair. The driver wants service, whatever it may cost him. The better class of products will last longer than cheap products, thus costing no more in the end, and will save many times their cost through their influence on the expense of maintenance and upkeep.

Oils for Various Uses.—In general, a thin oil should be used for light work at high speeds and a thick oil for heavy work at slow speeds. But in the engine cylinders the temperature also must be taken into account. The cylinder walls get hot, very hot, and the oil must be of high fire-test, in order to properly remain on these walls and lubricate them. With water on the exterior, the walls will be kept cool, and the oil need not be so thick, nor of so high a fire-test. But, if there are parts of them which are not exposed to water there is need for a good oil. If the cylinder is air-cooled, the

oil must be much higher test. For water-cooled cylinders the oil may be of 400° to 600° Fahr. fire-test. Such engines are believed to operate with walls below 200° temperature, but the pistons get much hotter than this, owing to the fact that they cannot part with their heat to the walls as fast as received. Air-cooled engines operate with walls at from 350° to 500° Fahr., or even higher, and should use no oil under 600° fire-test, while from 700° to 750° is better. The high-grade oil does not boil away, nor smoke, but remains on the walls and wears well. Very little of it is required, and it is almost impossible to do damage to any parts protected by it, because of the way it sticks to the surfaces.

Limitations of Lighter Oils.—The lighter oils boil away easily in the cylinder, and leave the walls dry. They force out easily, when a load is applied, and do not hold the metal surfaces apart. This permits the metal to wear rapidly, and so is productive of trouble. By vaporization, they mingle with the mixture, and make it too fat, with consequent smaller power and greater heating effect. If fed freely enough to keep the walls oiled, they form carbon, and foul the plugs; or pass into the air with the exhaust, as a very noticeable bluish smoke. Unfortunately, also, their effects are not regular, but vary with the temperature. When the engine is cool, the oil is simply an excess, passing away mostly as smoke, or fouling the plugs and walls. But, when hot, it reaches the vaporizing point, and then begins to make the mixture over fat, and irregular in action. The engine misbehaves, the cooling system is blamed, the operator is disgusted, and, even the car gets a bad name, because of this irregular action. If the critical vaporizing point of the oil is well above the temperature of the walls, there is no chance for it to cause such irregularity.

Action of Heavy Oils.—Aside from costing more, the heavier oils are darker in color, and, hence, popularly supposed to contain more "carbon." This is largely an error. All oils are hydrocarbons, and it is to their carbon content that they largely owe their lubricating ability. Bleaching with acids will give them a lighter color, but more or less of the acid usually remains, and is not advantageous to the metal surfaces. The heavier oils do contain more carbon, and need to be fed less freely. They are, therefore, less likely to carbonize the cylinder walls and the plugs than the lighter oils, which must be fed more freely. On the other hand, the lighter oil will boil away, instead of burning in many cases, just as gasolene or water boils away, and so leaves no deposit. But such action is proof of poor lubricating quality. The amount of free carbon contained by, and giving color to, the darker oils is so small that it need not be given much consideration. This can be easily proven by mixing a small quantity of lamp black (free carbon) with a light colored oil, until its color corresponds

with that of a darker oil. (Mix and grind the black thoroughly in a small amount of oil, first using a palette knife and a plate; as, otherwise, the black may remain in large particles.) The fire-test is the important part to most users, and can be roughly compared in the "stove lid test," which is made by dropping similar-sized drops of different oils, side by side, on a hot plate and noting their behavior. The one best able to stand heat will remain the longest. If, instead of a plate, we use a heavy bar heated at one end, the relation of the drops, which behave similarly with respect to the heated portion, will afford a rough comparison as to the heat-resisting quality of the oils.

Heavy Oils in the Cylinder.—The principal objection to heavy cylinder oils is the difficulty of turning the engine for starting. But, by "priming" with kerosene or gasolene on cold mornings, this may mostly be overcome. In water-cooled engines the use of an oil of too high test may cause some loss of power, due to this resistance to movement, but, generally, the perfect packing afforded by the heavy oil more than makes up for any loss of power by the stiffness of the oil.

Conditions of Oil and Grease Lubrication.—Oil and grease under service will lose their lubricating efficiency, owing to the fact that heat influence and service break down and destroy what is commonly called the lubricating body, thus permitting the moving metal parts to come into actual contact, instead of providing a protective film between them at all times. Further, when fed in excessive quantities, so as to leak out around the parts, oil and grease have a tendency to attract dirt, render the car unsightly, and seriously interfere with the action of the lubricant, by becoming merely a "holder" for abrasive particles of dirt that are accumulated. It is essential, therefore, that lubricants have the highest lubricating qualities and be also durable, permitting of use in quantities in no way excessive. To obtain the best service from lubricants, it is generally advisable to add pure graphite, which is many times more durable than oil or grease, and thus to permit these bodies to serve merely as holders or carriers for the graphite, which itself will provide the real lubrication.

Graphite as a Lubricant.—Graphite mixed with the lubricating oil or grease is strongly to be recommended in all parts of the automobile mechanism, and this for two very excellent reasons. In the first place, the graphite appreciably increases the lubricating efficiency of the oil or grease, thus actually saving oil expense. Such a consideration should greatly extend its use for automobiles. In the second place, it is desirable to use such an efficiency-increasing substance in a machine which is often driven and cared for by a person unskilled in mechanical requirements, and, hence, liable to forget to renew oil supplies as frequently as should be, or to bear *in mind* constantly the unescapable necessity of

feeding in correct proportions. In former years the use of graphitized lubricants was largely limited, for the simple reason that few, if any, commercial forms could be had in such a finely divided state as to pass easily through the feed holes of the usual oiler. These were liable to become clogged by caked particles, and considerable trouble was bound to ensue. Such difficulties were greatly aggravated by the fact that no method had been discovered for producing a real solution of graphite in either oil or water. Hence there was constant danger of precipitation. All these difficulties have been overcome, however, by the discoveries of Acheson, who has perfected a method, not only for producing a pure unctuous graphite from ordinary amorphous carbon in the electric furnace, but also of suspending it perfectly in a liquid. The latter result is attained by the process known as "deflocculation," whereby, as has been discovered, powdered graphite, mixed in a liquid charged with an organic substance, such as tannin, may be so finely subdivided by the action of the solution, that a perfect suspension is achieved. The inventor claims that the graphite is thus so completely subdivided that it is reduced to a molecular condition, and many of his experiments seem to argue to this conclusion. The lubricating solution is perfectly stable, the graphite particles having been found held in suspension for years, without precipitation. Such a process is highly to be recommended for graphite to be used in lubricating oils and greases. The furnace graphite may be mixed with any oil, and acts powerfully to increase its efficiency.

Where Lubrication is Necessary.—Every bearing where two pieces of metal run or slide on each other requires oil. By a little attention to squeaks and whistles around the vehicle it will be possible to locate and stop most of these noises, if not all of them, by the application of a little oil or grease. Grease is advisable where it can be applied directly to the spot or forced into place, for it will not run away. Neither will it run in where wanted, so oil must be used for most bearings. The quality of the oil is not so important on cool bearings unless they have heavy loads or high speeds. Frequent applications, rather than copious ones, should be the rule. The film of oil or grease keeps the metal parts from contact and wear, and thus prevents wearing out. By excluding grit and thus preventing grinding, the parts will endure for years.

Graphite and Greases.—In such connections, the use of graphite may be recommended. In many places where oil and grease will collect dust and grit, the use of graphite with only sufficient oil or grease to hold it, will make a lubrication second to none. Thus for spring leaves; first rub with a greasy, or oily rag, and then dust with graphite. The graphite will so fully fill the grease that it will not hold other dust. And the graphite is a superior lubricant, so that it prevents wearing and squeaking better than oil, where the

motion is slight as between spring leaves. While the oil or grease, will force out, the graphite is strong enough to carry the load; nor will it become thinner and squeeze out.

Amount of Graphite Necessary.—A small amount (1/8 of 1% by weight) of graphite mixed with oil is splendid for any service. It fills the pores of the iron, and helps to make a mirror surface which is nearly frictionless. It does not burn nor boil away, and is thus well adapted to cylinder use. It conducts electricity, however, so if the plugs are flooded with oil containing graphite they will cease to spark, but this is unusual, as will be seen later.

Lubrication of Cylinders.—There are two theories concerning cylinder oil. It seems likely that the first of these is fostered by people having low-fire-test oils for sale, assisted by those who prefer a light oil, because of the fact that an engine lubricated with a thin oil can be turned over for starting with less effort. These people contend that an oil should evaporate (boil away) when it gets into the combustion chamber, and that it should do this at such a low temperature that it does not disassociate ("crack") into its constituent elements of carbon and hydrogen, and deposit the carbon. It is, however, hardly possible in a well designed automobile engine, nor is it desirable from an economic point of view, to keep the temperature of the combustion space walls so low that this "cracking" action cannot take place. It may be regarded as certain that the heat is sufficient to crack any oil thrown into this space, and that the best way to prevent the formation of carbon deposits is to use less oil. Certain it is that the vaporization of the light oil leaves the walls bare and dry, exactly where they need lubrication the most, and where oil is needed for packing the rings to hold the high pressures from the explosion of the working charge. Further, this vaporization releases the hydrogen and makes the mixture over-fat and less powerful when the work is hardest and the most power is needed. It interferes with the setting of the carburetor adjustment, and should be avoided from this standpoint.

The other theory is that the use of oil is for lubrication and ring packing only. It is too expensive to burn and to cool with. If confined to its legitimate purposes, it will give better satisfaction than if a combination of services is expected from it. Therefore, cylinder oil should be of high fire test; sufficiently high at least not to vaporize and smoke off the cylinder walls. It should remain there and lubricate them. It should be able to stand the heat, and do its duty, instead of requiring a fresh supply at each stroke to replace that which smokes away. This means greater economy and smaller carbon deposits. In order that it may pack the rings and enable them to perfectly hold the gases and force of the explosions, the oil should have a considerable body at high heats. Thin oils do not pack the joints and easily *blow away, letting* the gases leak past the rings and over-

heat the walls and piston. It should have a high viscosity that it may stick to the surfaces to which it is supplied. An oil that wipes off easily cannot be a good lubricant for hard work. High fire test, high viscosity and ample thickness or body when hot are the essential requirements for a good cylinder oil. That such an oil makes the engine turn hard for starting is a small matter in these days of self-starters, and this stiffness can be overcome by flushing with kerosene when stopping, or by priming with gasolene when starting, if free starting is essential. It may be confidently asserted, however, that with the use of pure furnace graphite, the specified difficulties with either kind of oil may be practically neutralized. The advantage of the pure furnace product lies in the fact that it may be suspended in the liquid, and, from the fact that it contains no impurities, grit, etc., both assists lubrication by giving a smooth contact surface and by furnishing a body so advantageous in other ways.

Splash Lubrication for the Engine.—There is one common type of motor lubrication, *i. e.*, splash from crank case, the connecting rods dipping into the oil and churning this to a mist, which rises with the piston and lubricates cylinder walls, wrist pins, bearings and all parts. There are two common divisions in splash lubrication, one generally known as the constant level system, and the other a type of force feed to the bearings or crank shaft direct, with no overflowing. In the constant level system the oil is fed by a pump, generally through sight feed on the dash, and direct to the bearings, either through a hollow crank shaft or through leads to those points; or else is fed direct to the crank case, in which instance the splash is relied upon to lubricate all parts. The constant-level system has an overflow pipe at one end of the crank case, or, in some instances, in each compartment, keeping the oil at a certain definite level, which may or may not be subject to control by the operator. In such a case the oil flows through the overflow pipe, and, generally, through a screen or filter, and back into the reservoir, to be used over and over again. Exhaustive experiments seem to warrant the statement that the mixture of pure furnace graphite with the oil is distinctly beneficial in the fact that it acts both to extend the life of the oil, also to increase its lubricating efficiency to a very perceptible degree. Its use is to be strongly recommended with any make of oil, or with any system of lubrication.

Renewing the Oil Supply.—Manufacturers of cars will recommend that the oil be changed in the reservoir, where such a system is employed, after anywhere from 200 to 600 miles. This change is necessary, because of the destruction of the lubricating qualities of the oil. In the force feed system, with no overflow, the level is maintained by regulation of the number of drops fed by the lubricator in proportion to revolutions of the engine, and accordingly strokes of the plunger. In such a system care should be taken to see that the oil is kept

at a level that permits of splash of sufficient oil to properly lubricate and yet does not permit of splash of excess oil which will aggravate carbon conditions.

Lubrication and Carbon Troubles.—The influence of lubrication, both on compression and on carbon troubles, is very great, and somewhat related. If the level in the crank case is kept too high, or if the engine is lubricated by throw of oil from a hollow crank shaft, and too much oil is fed, carbon is bound to form, and can only be influenced, and not by any means prevented, by perfect piston ring action. If the rings play freely in the grooves and the cylinder surface is smooth, mechanical conditions of spring pressure, etc., being correct, there will be an almost perfect fit between the walls and rings, and, accordingly, the oil will be wiped back cleanly with each down stroke of the piston; thus leaving less oil in the explosion chamber to be burned, and become carbonized. It is frequently the case that the use of sufficient oil to provide for ample lubrication of the cylinder surfaces, particularly in the long stroke motor, means an accumulation back of the rings, with consequent gumming-up, which prevents free working of the rings, and thus interferes with the perfect fit between the parts. As a result of this, the oil is not wiped back cleanly, and carbon is accumulated. When deflocculated graphite is used in the oil a better fit between the rings and cylinder walls is provided and the wiping back of the oil is more thorough so that less oil will reach the combustion chamber to be decomposed and form carbon.

Graphite Lubrication in the Cylinder.—The use of furnace graphite in an engine oil produces material benefits. The graphite will provide the necessary lubrication of the walls, and thus do away with the necessity of splashing a large quantity of oil. Such furnace graphite is put up in packages containing charges for specified quantities of oil, and is itself in liquid form, making it necessary only to thoroughly stir it into the oil. When used in the lubricating system, the fine particles fill in microscopic irregularities in bearing, wall and ring surfaces, and provide a smooth finish. The deflocculated graphite will not precipitate in the solution, forming accumulations at the bottom of the vessel, and there is absolutely no danger of clogging up oil grooves or vents, or in any way interfering with perfect ring action. By smoothing the cylinder walls and perfectly lubricating the rings in their grooves, it greatly assists in effecting a perfect fit between the parts. Further, because of its efficiency and durability, the very fine graphite providing the real lubrication, it is only necessary to supply sufficient oil to serve as a carrier for this graphite, thus reducing the quantities used up, while keeping lubrication at maximum efficiency.

Superior Efficiency with Prepared Graphite.—In a circu-*lating system,* when furnace graphite is employed, the car

may be run, without changing the oil, several times the mileage possible when plain oil is employed. In a force feed system, with no overflow, using plain oil, it will generally be found necessary to clean the crank case out every few hundred miles. When this graphite is employed, however, a car may be run from 8,000 to 15,000 miles without the necessity of cleaning the crank case.

Effect of Graphite on Carbon Deposits.—Graphite lessens carbon troubles to the extent that it not only makes possible the use of a reduced quantity of oil, but, further, because carbon will not adhere as readily to a surface that is graphited, and accordingly smooth, as it will to the comparatively rough surface of even the most finely finished parts. Furthermore, the fine graphite seems also to have an influence in making carbon softer and more readily removed.

Carbon Deposit Explained.—Lubricating oil is a compound of hydrogen and carbon, their proportion varying but slightly in the different brands of oils, the average being 20% hydrogen and 80% carbon. When the oil enters the combustion chamber it is partially decomposed, as a result of the high temperature, and this, under conditions that prevent the burning of the free carbon, which appears as a fine dust, a portion of which is blown out through the exhaust, while other portions deposit on various parts of the cylinder and spark plugs. The deposit, thus formed by "heating" of the oil, is non-graphitic carbon, and is of a hard, asperous nature. On the other hand, the electric-furnace deflocculated graphite is soft and unctuous, vastly different from the carbon made as a result of the decomposition of the oil in the explosion chamber. Thus, it should be understood that the addition of such graphite to the oil does not increase the hard carbon content, but, on the contrary, lessens the possibility of its formation. Graphite not only forms a veneer on the walls of the cylinders and the surface of the piston rings, producing a better fit between the rings and cylinder walls, but also affords a more complete wiping down of the oil after each splash. Eventually, the graphite veneer becomes so perfect, the fit between the piston rings and cylinders so good, and, the wiping-down of the excess of oil so thorough, that little, if any excess oil is found in the combustion chamber, developing carbon trouble.

General Lubrication with Oil and Graphite.—There are many parts generally not provided with grease cups, such as rocker arms, valve stems, valve springs, etc., that must be lubricated with oil by means of squirt-can application. As these parts are frequently subjected to the influences of road dust, heat, etc., care should be taken to see that they are properly lubricated and yet that an excess amount of oil is not fed, for this would account for an accumulation of dust that would work detrimentally. It is advisable to use deflocculated graphite with all oil for squirt-can application;

the graphite here also rendering service for a much longer period than the plain oil.

Parts Grease Lubricated.—Many operators of automobiles regard grease as of minor importance, and even believe it a true economy to use a cheap grease for all parts. Such users do not take into consideration that grease used, for example, in the differential gears, is not only called upon to lubricate the gears, but must serve the fine bearings in the gear cases. Accordingly, a grease that gums up or loses its lubricating body, although it may not cause appreciable damage to the gears themselves, until it has been employed for a considerable period, will fail to properly serve the bearings, and, consequently, necessitate heavy expense for repairs. Therefore, the grease to be employed should be very carefully selected, (1) for its freedom from acid content, and (2) for its possession of efficient lubricating body. Grease containing cedar, fibre, cork, or such other materials should not be used, for the simple reason that, although it may silence gears, it will gradually wear the face of the gears, and rapidly work serious damage to the neighboring bearings. A grease containing pure furnace graphite is most serviceable, whereas a grease containing impure natural graphite is thoroughly detrimental, and should be avoided.

Opposition to the Use of Graphite.—While many bearing manufacturers have opposed the use of graphite, it is a safe assurance that their opposition is based on their consideration of a lubricant that contains impure natural or mined graphite, and not on the use of the electric-furnace product. Users of lubricants who desire highest efficiency and economy in operation can not too carefully guard against the use of impure graphite and make a demand for lubricants that contain the pure, gritless substance.

Lubricating the Transmission Gears.—It is the practice of some manufacturers at the present time to recommend the use of a heavy oil for transmission gears, while others recommend a mixture of cup grease and oil. According to the best practice, the transmission case should be filled up to the level of the main shaft, which will involve that the shaft and gears can carry the necessary grease for perfect lubrication at all times, both for the gears themselves and, also, for the bearings. Once in a season, or once every 10,000 to 15,000 miles, if furnace graphite has been mixed with the grease, the case should be rinsed and equipped with new grease. If a plain grease, and especially if an inferior grease, is employed, the case should be rinsed out every 3,000 to 5,000 miles. For regular operation, sufficient grease should be added every 500 to 1,000 miles to keep the level practically constant. Particular care should be used to employ a grease that is not so stiff as to permit of the gears cutting a path right through it, thus losing the required lubricating effect on the bearings.

Lubricating the Differential Gears.—The proper lubrication of the differential gears depends somewhat upon the construction of the gear case and rear axle. If the rear axle is equipped with proper grease check, so as to preclude any possibility of grease working along the axle and out on the brake bands, semi-fluid solution, such as is employed in the transmission gears, may be used to the best advantage. If, however, the construction is such as to permit of the grease working out, as suggested, a stiffer grade of grease should be employed. In either instance it is only necessary to fill the differential case until the bevel gear dips into the grease from one to two inches. This will permit of the gears carrying the grease up to the bearings, and will do away with the possibility of any excessive quantity working along the axle to the brakes. Also, when differential gears are noisy, either because of wear or faulty construction, a heavier grade of the semi-fluid will be found more efficient in silencing these noises. As in other parts of the machine, grease thoroughly mixed with pure artificial graphite solution will be found to possess superior efficiency. Grease lubricants containing chemically pure graphite are made in various consistencies, to meet all requirements of automobile operation.

Lubricating the Timing Gears.—The timing gears of most cars are to-day lubricated by means of oil direct from the crank case of the motor, and, accordingly, demand no extra attention. In some cars timing gears are in a separate case, which should be filled with semi-fluid grease, also, preferably, charged with very fine electric furnace graphite.

Couplings, Clutch Thrust, Bearings, Etc.—These parts are equipped for grease application, being entirely enclosed in leather jackets or in a metal housing. They should be kept filled with a grease sufficiently stiff to prevent its being thrown off by centrifugal force; and yet not stiff enough to permit the parts to cut through it, packing it in the sides of the housing. These parts frequently present most difficult lubricating problems to automobile manufacturers, for the reason that they are hard to get at, and accordingly, hard to lubricate. The proper consistency of graphite grease will be found serviceable here, as the pure, soft electric furnace graphite will lubricate perfectly under conditions which would not be met at all successfully by grease alone.

Lubricating the Wheel Hubs.—Wheel hubs having roller or ball bearings should be packed with grease of sufficiently hard consistency to prevent its wasting, and yet soft enough to do away with any possibility of gumming up around the rolls, and preventing their perfect operation. A soft cup grease, of a consistency between the semi-fluid and medium greases, is best for this purpose, and will afford lubrication for 1,500 miles, or in some instances even greater distances.

If electric furnace graphite is mixed with the grease, greater durability will be obtained, and it is only necessary to add oil at frequent intervals through the oil checks.

Steering Knuckles and Connections.—These parts should be packed with a comparatively hard grade of grease, preferably mixed with furnace graphite. As the parts are subject to accumulation of a certain amount of road dust, the grease used must have a good lubricating body to offset the effects of this, and the superior lubricating qualities of the graphite will warrant its use for this purpose, being durable and of great value under the trying conditions outlined.

Lubricating Cups.—For cup use the grease cannot be too carefully selected. It should be remembered that the cups on the engine, or on the jack shaft, feed parts that need most efficient lubrication, and will wear rapidly if improperly cared for. The cups on springs, and in other places, where subjected to road and weather conditions, need a grease that has sufficient lubricating body to offset the influence of the dirt and water. A soft cup grease with furnace graphite will not gum up in the cups themselves, or in the leads, and will, further, flow to the parts, and afford lubrication at a lower temperature than a stiff grease. When a very stiff grease is employed, it has practically no lubricating efficiency until the temperature of the bearing or part lubricated reaches a point at which it is caused to flow. A soft grease may be employed to advantage, if the operator will take care that he does not screw the cups down until they offer resistance, but, rather, gives one or two turns at regular intervals, and thus does not waste his grease, and provides perfect lubrication. If a stiffer grease is employed, greater pressure will be required to cause it to pass through the leads to the bearings, and it is apt not to spread. During extremely hot weather in the summer, it is sometimes necessary to use a stiffer grease than is recommended for general use, and during the winter months, when a car stands for long periods in a cold garage, or in the open, a soft grease will be found more efficient. Greases containing electric furnace graphite are made in various consistencies to meet all these requirements, and are extremely serviceable here, as elsewhere.

The Water-Pump Cup.—There is but one cup that, as a rule, presents radically different conditions from the others, and that is, the cup caring for the bearings of the water pump. Since the water washes the grease away, and destroys its efficiency very rapidly, a stiff grease should be employed. For all cups grease compounded with pure, soft electric furnace graphite has marked advantages, requiring less frequent attention, particularly as the graphite is itself not affected by extremes of temperature, and other unfavorable conditions.

Oiling the Fan Belt—While oiling, the fan belt should have *occasional* attention. If of leather, it must not be al-

lowed to become dry and hard. This will permit it to slip badly, and, if hard, it is likely to crack and break. Some belt dressing occasionally is advised. Castor oil is recommended, but often pure castor oil cannot be secured. A very slight amount of neats oil will soften the belt, and preserve its life, but much oil of lubricating quality will make it slip. Application of common chalk (school crayon) will help a belt or friction pulley to drive, unless it is too dry already. The tension of the belt should occasionally be noticed. A belt that is too loose slips and wears both pulley and belt, while one that is too tight throws unnecessary strain on belt and bearings.

Care of the Oiling System in Washing.—Care should be exercised in oiling not to force or wash dirt and grit in with the oil. The great need for oil often arises from the presence of dust and grit; and introducing more with the oil may do more harm than the oil does good. All oil holes, oil cups and priming cups should be covered or stoppered, or filled with felt or waste through which the oil may filter.

CHAPTER XXXII.

DRIVING AND CARING FOR THE CAR.

Care in Driving.—Having a fine car, a large part of its care must come in connection with its use. Do not abuse it in driving. Your intelligent horse slows up at the corners and rough spots. He slacks at the gutters and railroad tracks. Cultivate a like intelligence, and, if your car can be thus controlled, as most good modern cars can, do likewise. The racking of the body, straining of the springs and axles, and the pinching of the tires take place on bad spots. The comfort of the passengers alone should prompt such action. Many an intending buyer has been deterred from making a purchase, simply because the demonstrator did not take care of the vehicle, and drive "sweetly." The time is not many years back, when the average car could not be easily controlled. To slack up for a street crossing meant to release the clutch, or, possibly, change the gears, because many engines were not flexible enough to permit much change of speed, and, when under way, the driver tried to keep them going, in order to avoid the loss of time necessary to get under way again. Fortunately few such cars are now sold. The light high-powered car of today can throttle down almost to a walk, and get away again quickly, and with no other effort on the part of the driver than to twist the throttle. Even the spark is often not changed for considerable change of speed. In fact, with many magneto-ignited engines, the spark apparatus is not provided with a spark advance lever.

The Necessity of Cleanness.—Avoid mud wherever possible. It not only gets everywhere about the car, making cleaning more difficult, but water and mud lubricate the rubber surface of the tires and render puncture more easy. You can easily test this by trying to cut rubber with a knife, first dry and then wet. Most modern cars have their mechanism very well protected from mud, so that their operation is not much affected by the presence of mud. In fact, it is probably true that dust is more destructive to the mechanism than mud.

Washing the Car.—But the dirty car will not be so enjoyed, nor attended to so carefully nor so often, as if it were kept clean. On this account, as well as for tidiness and fine appearance, the car should be kept clean. And this cleaning should be done as soon after use as possible. The ammonia, alkalis and acids in ordinary street mud attack varnish and fabric, and do damage, even when apparently dry. The sun's rays fade and shrink the paint and wood, as well as the leather or fabric, so the car should not stand

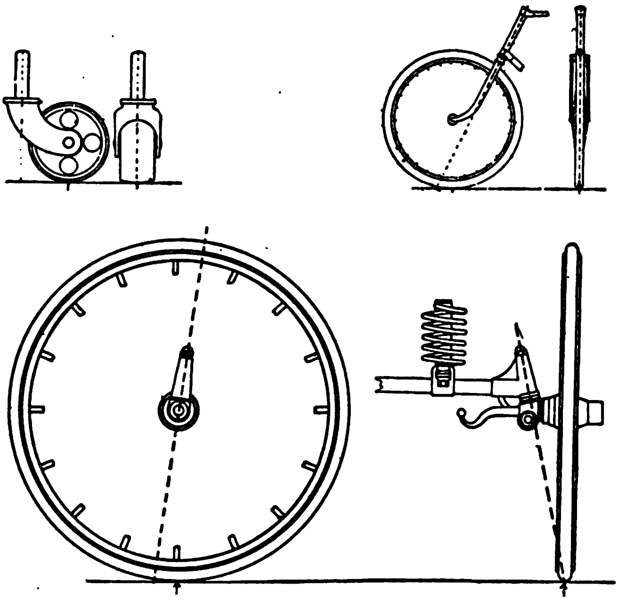

Fig. 32a.—Diagram illustrating the best approved method of applying the easy castor or bicycle movement to the steering of an automobile. The steering stud pivot, inclined inward and backward, brings the centre of rotation to a point just ahead of that at which the wheel touches the ground, thus accomplishing the equivalent of a true castor movement.

needlessly in the sun. Wash it immediately on coming in, especially while the varnish is fresh. After the first month or two, the varnish becomes less susceptible.

Avoid High Pressure in Washing.—Use plenty of water, but not at high pressure. Much force to the stream will drive the grit right into the varnish, like a sand blast. Further, it will drive the water into every joint and crack and soak up the parts that are likely to be damaged. Glue, nails *and screws* will not hold wood parts together, if water is *constantly* driven into the joints. Leather, cloth, and even

hair, rot and deteriorate. Rust and mold often follow injudicious washing. Let the hard spots of mud have time to soften by soaking. Do not attempt to rub them off. Or, if rubbing is necessary, let it be the lightest possible. A sponge on the end of the hose is good but a sponge alone can be used if a hose is not to be had. But use plenty of water.

Removing Grease Spots.—Watch out for grease spots. These should be removed with a soapy cloth. Avoid strong lye soap. It will cut and deaden the gloss of the varnish. Most carriage houses sell "neutral" soap, which has little, if any free lye. Some washers use a little kerosene to remove the grease. This is better than nothing, but probably not so good as a good soap. Be careful not to spread the grease about the surfaces to be cleaned by carelessly getting it on the sponge. It will collect dirt at once and look dingy. Having removed all mud, wipe off the drops of water with a "chamois," or "wash leather," of sheepskin. This is soft and very absorbent. Soft cotton cloths will serve, but are likely to leave bits of cotton on the surface, and also to drag grains of sand and scratch the varnish. The fine appearance of the work will largely depend on the amount of wiping it gets. It must be made absolutely clean to look well. This particularly means that the corners and crevices must be well cleaned. Some washers use a polish on the cloth at the last rubbing. This acts somewhat as a thin coat of varnish. But it must be quick-drying, and very thin. After washing see that the cushions, curtains, carpets and similar parts are cleaned, and absolutely dry, before being put back into the vehicle. Curtains and aprons should be kept rolled, not folded. They will keep clean longer and not break or look dirty in spots, if rolled.

Body Polish.—A good car should be well kept, and, to keep the paint and varnish looking fresh and clean, a good polish is necessary. Unless one has compared a car before and after polish has been applied to it he will not fully appreciate the difference. After a car has been carefully washed and dried, it is wise to go over it with a soft clean cloth and just enough polish to dampen the cloth. This takes up the slight dirt remaining, and the polish tends to fill any checks or cracks in the varnish and thus preserve the varnish and paint. Many washers use kerosene as a body polish, but this is decidedly bad, as kerosene cuts the glossy varnish surface and soon has the car looking badly and needing a new coat of paint. While it may not be possible to tell the difference the first time or two that kerosene is used, the fact that the varnish deteriorates quickly is good evidence that a mineral polish is being used. The base of the only safe polishes is linseed oil. This is the one great paint oil, and has proven its merits repeatedly. It would be *too thick to* use as a polish without thinning, and would

not dry quickly, but would catch the dust and soon coat the car with a rough surface. A good polish is made of two-thirds linseed and one-third lemon oil. Turpentine may be substituted for the lemon oil with almost equally good results. Some people use vinegar instead, and alcohol has been recommended. The linseed oil should be "boiled," because this makes it dry quicker.

Cleaning Freshly Varnished Vehicles.—These remarks apply to the vehicle in general. But the freshly varnished vehicle needs even more attention. The surface is not of glassy hardness but is rather waxy, because varnish is wax, or gum. Each particle of dust on this surface tends to settle into it, and, when removed by washing, will leave behind the dent where it laid. This destroys the smooth surface and glassy luster. But if removed quickly, the dent does not have time to become deep, and the still soft surface will resume its original shape. So a new vehicle should be washed frequently. If it has been out in the sun the varnish is soft, and quite susceptible. Washing cools and hardens the surface, and is, therefore, beneficial. The fresh varnish is easily attacked by ammonia, so any spot of mud or water will discolor it, and washing will not remove the spot. In this case use a little linseed oil. This may be thinned with alcohol or turpentine, or used without thinning. The oil restores that element cut out of the varnish by the alkali.

Treatment of Cracks and Bruises.—While washing, watch out for cracks or bruises that will allow water to get into the unprotected material underneath. If such are found, be sure they are dry, and rub linseed oil into them fully, wiping off all excess. Where the water will cause the wood to shrink, and swell, and rapidly go to ruin, the oil will swell it back to its original position and prevent change.

Cleaning the Top.—If the top is of leather, water only will clean it. If very dirty, soap will not hurt it, but it is not advisable. Soap is not good around rubber tops. Leather tops should be kept up, in order to keep them from becoming wrinkled or creased. Cloth or rubber tops are not so liable to look bad after being folded, but even they should be kept up when in the garage. It is better to have the dust that settles, on top of the top, instead of inside it, and the vehicle. Then, if the top is up, it can be seen inside and out, and be known to be clean.

Cleaning the Mechanism.—In general the mechanism is housed so as to keep out the dirt. In cleaning for appearance, be careful not to force the dust and grit into the joints. It is better to let the joints of the various bearings go uncleaned than to force needless grit into them. One great advantage of cleaning the mechanism is that a good opportunity is had to inspect the various parts, as they are cleaned. Removing the dirt, not only permits such parts

to be seen, but it brings them to one's attention. While cleaning, one should have wrench and screwdriver handy, so that loose nuts or screws can be tightened. And, if they evince a disposition to get loose again, see that they are fixed permanently.

Methods of Securing Screws.—Nuts can be locknutted or cotter-pinned. Screws can have their heads bored and fastened in place with wire. If they have heads that will not permit this, they can be set in varnish which, as soon as dry, will hold them firmly. This is for wood. For metal screws, shellac varnish, allowed to become practically dry on the screw, then softened by heat, and sent home while hot, will hold. Even chewing gum treated the same way will serve. Heat the screw and dip it into the gum till its point is covered. To remove such a screw heat may be necessary. The end of a hot iron rod against the head will serve.

Need of Watchful Care.—More extensive disorders should be noted and repaired promptly. The main thought is that the car should be known to be right, if frequent inspection will accomplish this. It is well to get into the observing habit, and always keep an eye open for possible looseness or broken parts. It is the unexpected thing which always happens. Yet it seldom happens without warning. The peculiar crack in the paint, noticed while cleaning, may be warning of a break beginning at that place.

Care of Tires.—Next in importance to the vehicle itself are the tires. If the wheels are jacked up for washing, as is best, the mud can be worked from the hub toward the bottom, and the tire turned round so that all parts of it pass inspection at the top, where the light is good. Watch for cuts, rim cuts, sand blisters and incipient bursts, and of course, for the dreaded tack or nail, which is likely to be found at any time. Remove the nails, lest they be driven deeper and do damage. Note where they were, and mark with chalk or lead pencil. If the tire deflates soon after, it is reasonably evident that the point has punctured the air tube, and the marking will locate it for repair. Fill the holes and cuts with "mastic," or one of the various rubber compounds prepared specially for this purpose. This will keep the water out of the fabric, and prevent the rotting due to the presence of water in the fabric. Of course, the cut should be cleaned and dried, as fully as can be, before closing.

Rim-Cutting.—Rim cut dangers demand investigation of the rim, to remove any rust particles or rough spots, which may be the cause of the cutting. If the tire is much rim-cut, have it repaired by a vulcanizer. Sometimes, rubbing the incipient cut with talc or graphite will stop the cutting. Different inflation is usually indicated by rim cutting.

Sand Blisters and Bursts.—Sand blisters begin with small holes down to the fabric, into which the sand and dust wedges, and slowly lifts the rubber from the fabric. Remove the dirt with a button hook and fill with "mastic." If the blister is quite large, and the entrance not easily stopped, it will often be beneficial to open another hole into the blister near the side of the tire where the dirt can get out. This will usually prevent further filling and extension of the blister. Have it repaired by vulcanization at the earliest opportunity. Bursts usually manifest themselves by protrusions like sand blisters and indicate that the fabric is weakening under that point.

Repairs for Bursts.—They should be vulcanized, but may be temporarily repaired by slipping a strip of canvas around the air tube and with its ends outside the rim. Inflation will force this up against the tread, if about in place to begin with, and the beads will hold the ends. The loose portions can be cut off. If "frictioned" canvas can be had at the repairer's for this purpose, it will stick to the casing better, and wear longer than plain canvas, and be good for many miles of service. In the absence of canvas, the tire may be partly deflated, and wrapped with stout string. Over this put a wrapping of tire tape, several layers thick and good service will follow for miles. The string furnishes the strength, and the tape, the wearing surface. Leather or pigskin shoes are made for lacing to the outside of the tire, and still other shoes for placing inside.

Care of the Tire Casing.—Keep gasolene or kerosene away from the treads of tires, except for cleaning. Kerosene, or any light oil, will soften the rubber, and remain in its pores for many days, during which time the rubber has little strength and wears away quickly. The heavy oils, like cylinder oils, do not enter the rubber so freely, and so do little damage, but should be kept off the tires, if possible. Use talc or graphite freely on the inside of the casing, but not in such quantity that, if wet, it will form chunks. Its purpose is to avoid friction between the casing and tube, and graphite is better than talc, although being black is less pleasant to work with. Particularly notice the inflation after every stop. A single block over loose sharp stones may fill a tube with cuts, if the tire is deflated. A slow leak, while running, will usually manifest itself by the occasional bump the car gets, but if the tire deflates while standing, there is no air to save the tube.

Care of the Wiring System.—The spark system is the most delicate and elusive part of the modern auto. With modern wires, and good insulation and proper supports, there is very remote likelihood of trouble in the wiring system, until it gets old and worn. But even the best wire will burn bare quickly, if it gets in contact with a bare exhaust pipe, or wear through, if rubbed by the fan or fly-wheel.

Consequently, occasional inspection of the wiring is advised.

Testing the Spark Plugs.—But the source of current and the plugs need most attention. The plugs may crack, or develop a leak, due to the alternate heating and cooling to which they are exposed. Or, they may leak through the carbon which covers their insulation, carbon being a fairly good conductor, and better when hot than when cold. It is quite common to test the plugs, and the strength of the spark, by placing the plug on the head or other part of the engine, and causing the spark to pass. Many assume that, if the plug will spark when outside of the engine, it will spark inside. This is not a proper conclusion.

The "Outside" Test.—The outside test is of value mostly for judging the spark heat. When in the cylinder the compression makes the air thicker and harder to be passed through by the electrical discharge. So, also, it is harder to jump the 1/32" gap inside the cylinder than 3/8 of an inch outside. On this account, it is good practice to insert a piece of mica, glass tube or goose quill, between the points, when the plug is out, in order to see if the spark will pass around it far enough to amount to a distance of 3/8", or thereabouts. If so, it is certain that there will be a good jump inside.

The Running Test.—Another test may be made while the engine is running. Drive the bend of a common hairpin into a common file handle, and spread the points out to form a "Y." Rest one point of this simple tool on the engine head, and bring the other near to the top of the plug. The spark will jump a distance of 1/4 to 3/8 of an inch, rather than jump the gap inside, if the plug is good. But if there is a leak, it will go across the leak and not jump a large gap on the outside.

Cleaning a Fouled Plug.—If the plug is much fouled by carbon, it must be cleaned. Usually this can be done by washing with gasolene, or scraping with a piece of tin or copper. The use of sandpaper for cleaning is not good, as it destroys the smooth glassy surface, and assists the carbon to stick next time. An excess of carbon should be taken as an indication that too much oil is being fed, assuming that the engine has not been missing fire. But if missing is frequent, the oil will work above the rings, and show fresh and uncarbonized on the walls and plugs.

Care of the Magneto.—Magnetos are so well built nowadays that they are as dependable as any other part of the vehicle. They are not likely to need attention, other than to see that they are running properly. Where they are friction driven, a surplus of oil on the friction surfaces may interfere with proper driving, and need cleaning.

Care of Chemical Batteries.—With batteries it is different. A battery is a source of pent-up energy, constantly trying to escape. Offer it a path anywhere, and out it goes, as fast as the path will allow. Further, all batteries have some internal leak, or loss, and, in time, this will allow the energy to disappear. On this account, storage cells should be recharged once per month, whether used or not. And dry cells should be looked on with suspicion, after they are two months old. Care, therefore, should be taken to keep the tops of the cells clean, lest something collect thereon, and offer a path for the current. The layer of dust that will gather, wet with electrolyte oozing from the cells, will allow some leak to a storage cell.

Avoiding Short Circuits.—Never file metal over the cells, for the filings will conduct almost perfectly. Never place anything on top of the cells. Beginning with gloves or other harmless articles, somebody soon forgets and piles the tire pump, or the pliers, or other metal article, right across the binding posts where it will offer the quickest path for the current. This not only runs out the current in a very short while, but a metal article may be heated hot enough to set fire to things that it may touch. Dry cells may be short-circuited by standing on a wet surface. If, by any possible chance, they may get wet in washing the vehicle, they should be inspected after each washing.

Testing Cells.—Storage cells should be tested by using a voltmeter, never an ammeter, because the great available current would almost certainly ruin the ammeter. The voltmeter is advocated for dry cell testing, but, if used, should be when, or just after, the cells are used. If the voltmeter is applied after the cells have been idle a short while, it will register full voltage and be misleading, due to the fact that, on standing, the dry cell seems to rest up and shows full voltage. The ammeter shows the full flow of current on short circuit.

The Use of the Meters.—At first contact the needle will throw high because of the stored condition, but it will quickly fall to normal short-circuit flow. This short-circuiting of the cell is harmful, and runs out the energy very fast. It should, therefore, be continued only long enough to get an idea as to about the position of the needle. Since the use of the meter is to learn the condition of the cell, the actual reading is of little importance. The proper way to use an ammeter in connection with dry cells is to put it in the coil circuit. With the coil as a resistance, or load, the flow of current will be slight, but it will indicate the ability of the cell, just as truly as if tested on short-circuit, and it will not unduly drain and damage the cell. Each cell should be tested separately, of course. This does not require disconnecting the wiring, but simply that the meter circuit does not include more than the one cell and the coil, if

used. Instead of the coil, some prefer a small battery lamp for a resistance. The fact that lamps vary in their conducting ability, and are fragile, and, therefore, likely to be broken and require replacing by another which may be different, would seem to make the coil resistance preferable. The coil is always present, and needs only to have its wires disconnected from the battery, and one of them connected to the meter. The other, and a wire from the meter, constitute the testing points to be placed against the proper poles of the cells.

Required Current Strength.—With the usual jump spark coil the use of cells showing under 6 or 8 amperes is not advised. But with the single spark devices the drain on the cells is not so great, and they will often run down to 2 or 3 amperes with fair results. The make-and-break spark coils will often use the dry cells down to this low limit, although many people suppose that the make-and-break requires more current than the jump. One great cause for this difference of opinion lies in the fact that many coils are very cheaply built, and having but little wire in them, must have current to make up. Each user must, therefore, learn at what point his coil will cease to give good results, and test his cells to that point.

Renewing the Battery.—Faulty cells should be taken out. Often a battery will do better with a dead cell out than with it in. If handy, replace the removed cells with others as nearly like the ones remaining, in point of use, etc., as possible. This keeps the whole set alike. To replace with new cells is often necessary, but if the old ones are well run down, it is better to throw them out, and use all new ones. There seems to be some tendency for the weak cells to act as drags on the new. Often while quite fresh, a smaller number of new cells will do the work, and, as they lose strength, the old ones, in the order of those in best condition, can be connected up with them.

Conditions of Current Generation.—The flow of current, in theory, depends on the voltage, but a large amperage, as given by a fresh cell, seems to quicken the flow, and some users make it a practice to use the number of cells to suit the coil, while fresh, and increase the number, by one or two, as they get older. But, in no event, should the number be greatly increased, lest the insulation of the coil be broken down.

Drying Wetted Cells.—If the bottoms of the cells get wet, they should be set out to dry separately. If left connected, there may be some leak from one wet zinc to the next, forming a circuit. Dry cells should never be carried on metal floors, or on bolt or screw heads, lest the jolting wear out the paper covering, and allow the cells to short-circuit through the metal below.

Setting up a Battery.—Cells should not be set in their places haphazard, but care should be taken to see that the zinc binding posts of two cells do not get together. If set with system, it is less likely that they will be connected up wrong. A single cell, connected up in the reverse way, neutralizes another cell, and does the battery damage.

Guarding the Wiring Connections.—The cells should be free from shaking while in use. This motion, even though slight, will likely break the flexible wire connections inside the insulation, and be the cause of a very mysterious missing of sparks and a failure of current. Often, when nearly broken in two, the connection will show a spark, but will not transmit enough current to properly saturate the coil, and so will not give a good spark.

CHAPTER XXXIII.

HOUSING THE CAR.

Housing the Car.—Every auto requires some keeping and some care. This presupposes a garage. But the garage can be as simple and cheap, or as costly and pretentious as one may desire. Many a physician leaves his auto out in front of the house all night, ready for an instant start, when called. It is one of the advantages over the horse, that it is ready to go at any time, day or night, and can be left standing for hours without attention or worry. If provided with a top, there is usually no need to cover it, but if not, a heavy canvas tarpaulin, such as can be bought of second-hand canvas dealers for 8 or 10 cents per pound, can be thrown over it, and will keep it dry, even in a storm. The weight of the heavy canvas will hold it down, with no need to fasten it; and it is so easily taken off, or applied that it will be often used when the garage is not close by.

Advantages of a Private Garage.—If one has any room at all on one's lot, it is advisable to have one's private garage, and so always have the auto at hand, ready for use and free from the abuse too often encountered at public storage places. In buying a car one considers the price most of all, and seldom gives a thought to the after-cost. The fact that it needs neither hay nor oats is remembered, but the equally important fact that it needs fuel, oil and care, is too often forgotten. As the man who plays a game gets more enjoyment out of it than the spectator, so the auto-user, who cares for his own machine, will get more pleasure out of it, than the man who simply drives it, when it is in order, and grumbles when it is not. As he drives it every day, he notices its behavior, and, at the next opportunity, remedies anything that seems not to be just right. In this way, he keeps it tuned to the highest pitch, and always in fine shape. By fully knowing it, he not only keeps it in perfect order, but it will do for him better work, and more of it, than if neglected, or entrusted to the shop mechanics,

who, no matter how conscientious, can not know its condition so well as the observant intelligent driver.

The Simplest Garage.—A roof with two or three sides, to protect the car from storms will serve quite well for a garage, if nothing better is available. Doors insure greater safety to the tools, and such parts, as can be carried away easily, but are not a necessity in many localities. It will thus be seen that the shelter can be made very cheaply, if necessary. The same may be said of the equipment. Washing may be done with a pail of water, and a rag. The tools that come with the vehicle are sufficient to do most of the work required in caring for and adjusting it. But a better equipment adds much to the ease and pleasure of taking care of one's faithful machine.

General Requirements in a Garage.—The building should be at least large enough to house one machine, with room to get around it. If it can be driven through with doors at each end, it is more convenient, than if open at one end only. In fine weather the doors may be left open, letting full ventilation and light upon the work being done. If it cannot be driven through, a turntable is very handy, so that the car can be headed ready to go out, without the necessity of backing. The turntable is also handy to head the car toward the light, when a dark job of work is to be done. Windows on the sides, or in the roof, should be provided. In short, the light should be plentiful. Many things pass unnoticed in the dark that would be seen and fixed, before they become serious, if there was ample light. The cleaning is likely to be badly done in the dark, and artificial light is not to be compared with daylight. If the floor is of cement or asphalt, it can be used as a washing floor. Otherwise, it may be necessary to wash outside.

Keeping the Garage Dry.—If the garage is not heated it is hardly advisable to wash indoors, for the whole building will be damp, and, being damp, keeps the auto damp, and rusts the metal, softens the glue, molds the cloth and leather and swells the wood. Moisture is very destructive, and should be avoided, so far as possible. If heated, the moisture soon dries, before much harm is done. The cleaner, if careful, will wipe off every bit of water from the various corners with his chamois, before pronouncing the job finished. In fact, much depends on his care and faithfulness.

Lighting the Garage.—Given good light, he can not only see where the dirt is, but can see to get it, and the water, off the rig, before quitting. Frequent varnishing also keeps the rig looking well, also keeps the water out of the joints. This subject of cleaning is so vital to the good service of the vehicle, that it should not be neglected. Proper provision should be made to properly and frequently clean it. The user's pride is largely in proportion to the appear-

ance of his equipage, and he will not be likely to take care of the mechanism, which does not show, if he does not keep a clean exterior.

The Floor of the Garage.—If the washing is done inside, a floor of asphalt, or even of cinders bound together by common gas tar, will not hold water nor remain damp so long, as one of cement, and is not expensive. Hose should be provided to get at all sides of the vehicle, unless a turn-table is used, in which event the rig can be turned around to bring every side to the front and light. The hose should have a sponge, or cotton wiper, on the nozzle, so as to prevent contact of the nozzle with the paint, and to soften the force of the water. Less water is used, and the dirt soaked off, rather than driven off. If the water can pass through a coil of pipe exposed to a flame, or to hot water, it will take the chill off, increase the solubility, and make washing a more pleasant job in cold weather. Never use hot water.

Gasolene and Oil Storage.—Ordinarily, it will be found economical to provide storage for gasolene and oil, so that these necessities can be bought in barrel lots at least. While, in some cities, the oil dealers will not sell in bulk to the consumer, in most places the price depends on the quantity, rather than on the buyer, and the retailer's profit can be largely saved. Gasolene should be stored in the ground, and pumped up as needed. This keeps it from exposure to the varying temperatures of the air, with consequent expansion and contraction of the vapor in the tank, and loss of vapor at each expansion. It is practically safe from fire in the ground, and the garage can burn down over it, without burning the fuel in the ground tank. It also uses space of no value, when buried. The tank can be a second-hand kitchen boiler, carefully tested, to be sure it has no leaks, although known not to be capable of standing usual water pressures. Better tanks, with every convenience, cost more and are, perhaps, slightly more handy.

The Work Bench and Tools.—A bench, if only one narrow board, should be provided, and a strong vise mounted on it. The tool equipment will depend much on the man. Many office workers get great relaxation out of the work that they do in the garage, attending to the machine, and, if the time can be spared to do the work, a complete equipment is advisable. A hammer, a hatchet, a cross-cut saw, a rip-saw and a compass, or key-hole saw for wood, a hack-saw with some extra blades for metal, some drills assorted, for metal with a small drill brace, some wood bits with bit brace, several sizes of cold chisels and wood chisels, and a few awls, punches, files and screw-drivers, are among the most necessary tools for doing odd jobs in either wood or metal. A hand power emery wheel for rough grinding, or sharpening, and a whetstone for fine edges, should be included. In general, it is wise to provide tools only as occasion requires.

In this way one gets what is needed, and no more. A small torch for blow-pipe work, soldering or small brazing, is a very valuable tool.

Forge and Machine Tools.—A forge for heavier heating and forging, a small foot-power lathe, or, better yet, one driven by an electric motor, can be used for almost every job about the auto. It can serve as a drill-press, or, fitted with a polishing wheel, will do much to keep the bright parts of the car in fine condition. An electrically-driven flexible shaft will carry small polishing wheels right to the bright parts of the car, and permit them to be polished in place, in but a fraction of the time required to polish by hand-power. This line of suggestion could be extended almost indefinitely. It all depends on the amount of money, time and space available to fit up and use the equipment. Many a man would rather do his tinkering under a shady tree by the side of the country road, where the air is pure and perfumed, instead of in a stuffy dark building. Such a spirit needs neither advice, nor much equipment.

Heating the Garage.—The heating of the garage in winter is a problem. Proper attention cannot be given to a cold car. Washing cannot be done, because the water freezes on the metal parts, and cleaning will not be carefully done, because the worker suffers from the cold. If the garage can be alongside the house, heat can usually be carried from the house. Steam or hot water coils are to be preferred, of course. But, if the garage is well made and reasonably tight, and has an open door into a warm basement or warm part of the house, it will be warm enough, without other heat. If it must be heated by a stove, the use of an oil stove with no chimney connection should be avoided. Gasolene vapor is heavy, and drops to the floor. A common stove with chimney carries off burned air and draws in a constant current of fresh air from every crevice. This circulation will carry off any small amount of vapor without danger. Since the vapor lies on the ground, if gasolene is spilled the doors should be opened at once, and the fullest ventilation secured. Sand, or any absorbent, will cover the liquid, and prevent danger, but sand is not good around machinery, so that common flour or meal is probably as good an available extinguisher as anything short of the chemical preparations sold for this purpose. Water does not help to eliminate gasolene, but scatters the liquid, and increases the size of the fire, if it happens to ignite. Wet canvas, or wet blankets, will smother an oil fire quite well.

Disadvantages of Lamp Heating.—When the room is not heated, it is usual to put a kerosene lamp on the floor, under the engine, so that heat from the lamp keeps the engine warm, and ready to start. If there is any leak or escape of gasolene, this is quite likely to take fire, so that the lamp habit is not to be encouraged. If a lamp is used

to keep the water from freezing, considerable worry results from the fact that the lamp may go out in the middle of the night, and let the radiator or engine freeze. There is always some danger that, even though the engine is kept warm, the water circulation may be so slow, as to allow the radiator to freeze on cold nights. It is better, therefore, to use an anti-freeze solution, and not have to depend on a more or less dangerous sort of heat, such as the lamp provides. Where the garage has a room adjoining, some users, have rigged a stove in the adjoining room, and fitted it with a water coil, which was extended to the garage. This gives the necessary heat, with no loss of room, and a practical certainty of safety from fire.

Flushing the Engine.—The engine can be kept free, and easy to start, by flushing it with kerosene on arriving at home. This should not be applied immediately, but after the engine has slightly cooled. It cuts and washes out the oil, and clears out the carbon. If suitable priming cocks are provided, this flushing may be done with a common squirt can, but, in some cases, an oil gun is preferable. If the engine is too hot, however, kerosene will at once evaporate, and smoke away, leaving the walls of the cylinder dry and productive of much friction, with danger of cutting before fresh cold oil can get to them, when the engine is again started.

Working Pits and Raised Tracks.—Some garages are fitted with a pit for work under the car, but, nowadays, there is usually not much call for such work. Also, a pit is a dirt-catcher, as well as a dangerous receptacle for gasolene vapor, which is hard to ventilate out, and, therefore, dangerous. Instead of the pit, it is well to use a raised track, on which the car can be run, so as to stand several inches, or a foot or two, higher in the air. This track can be stood against the side of the room, or out of doors, or hoisted to the ceiling, when not in use. Some cars are sufficiently accessible on the under side, when hoisted one end up into the air, using a set of blocks and a suitable rope. This usually permits better light on the work than the pit. In the absence of these things, a wide board, on which the workman can lie, provided with casters, so that it can be run under the car after the workman is on it, greatly facilitates getting at parts under the car. The board can have a head rest, and both saves time and adds comfort. These boards, called "creepers," can now be bought at very reasonable prices.

CHAPTER XXXIV.

SKIDDING OR SIDE-SLIDING.

Skidding and its Dangers.—No subject connected with the automobile has attracted more attention than skidding, and received less benefit from the thought and experimenting expended on it. To feel that one's grip on the road surface has broken, and that one's direction of travel has become a matter of chance, is a sensation that the average person will neither relish nor seek to repeat. The helplessness of a skidding auto is that of the proverbial "hog on ice." Putting on the brakes, pulling the clutch, juggling the steering, and any other stunts, are all of no avail, when the wheels have no grip on the roadway. On a perfectly smooth surface, like a lake of ice or a wet asphalt park, skidding is perfectly safe, and becomes an amusing sport. But, generally, the conditions are not safe, and the danger of skidding is a constant worry to the driver, when on icy or greasy roads or streets, unless his wheels are sharp shod with chains or studded tires.

Search for the Cause of Skidding.—So frequently does skidding cause damage, and often death, that engineers have their attention on it almost constantly, but no subject offers less hope of solution, so long as present auto constructions are followed. To many the matter is one of obscurity, with neither the cause nor the cure in sight. Yet it is a simple problem, and, in time, will work out its own solution so simply, that we will wonder why we never thought of it before. In fact, in its very simplicity lies the reason for its tardy recognition. Engineers have sought for the cause in the differential; in the brakes; in the steering, and in many other parts of the vehicle. Learned dissertations have been put forth to show that skidding will not occur if the brakes are equalized, so that both rear wheels receive just the same amount of retarding effect, when the brakes are applied. But, in spite of these theories and experiments, cars *go skidding* around, swiping into curbs and street cars, to

the danger and damage of all concerned. Needless, indeed, is it to enlarge on the fact that skidding is far too frequent, and that aside from tire chains or studs which are more or less objectionable remedies, nothing is being done to solve the problem.

Conditions Involved in Skidding.—To get a full understanding of the matter, it is necessary that we first understand something of friction itself; because skidding is caused by lack of friction. Simply stated, friction is that resistance to relative motion found between two bodies in contact. As generally understood, there are two degrees, often termed "kinds," namely standing friction and moving friction. The former is the resistance to motion between two bodies in contact, and not in motion, with relation to each other. The latter is that degree, or remainder, of friction, which is found to exist between two bodies in contact, but also in motion, with respect to each other. In short, the friction of motion differs from the standing friction only in degree because some of the standing friction has been overcome by the force which causes the motion, and, further, because the parts in motion do not get the full opportunity to fit into each other, as standing bodies do, and, so, do not possess the same amount of grip or friction that exists between two bodies standing in contact. This fact is well known to railroad men, who know, by daily trials, that, so long as the wheels do not slip on the rails, the brakes can be applied much harder, and with greater retarding effort, but that, if the brakes grip hard enough to slip the wheels, they must be considerably released, before they will again permit the wheels to slip under them, and to again acquire their usual grip upon the rails. This same example shows that the wheel of a railway car is in standing friction contact with the rail, under usual conditions, and resists slipping on the rail practically as much, when rolling, as when standing still.

Standing Friction of Rolling Wheels.—In fact the bottom of a wheel is not in motion, but stands on the rail, or ground, as truly when the wheel is rolling, as when still. This is easily proven by fitting a fine point in the tire, and noting that it makes a fine hole in the ground, or roadway, whereas it would make a scratch, if it was in motion, with respect to the ground. These examples could be much continued, but seem sufficient to make it plain that a rolling wheel is in standing friction, with respect to the ground, and that standing friction is greater than moving friction.

Skidding as Moving Friction.—The application of these facts to the skidding problem follows closely. So long as the wheel maintains its usual course, the friction is that of the standing wheel, and all is well. But let the friction between the wheel and ground be destroyed by excessive application of power, whether from brakes or engine, and

the standing friction is lost. Then, the relation of the wheel to the ground is that of two moving parts, and, if the ground is icy or covered with greasy mud, the wheels move with great freedom in any direction, regardless of the steering efforts of the driver.

Effects of Moving Friction.—It is hard to understand that, when the usual friction is broken down, the wheels may move practically as easily in one direction, as in another, but such seems to be the case. Every mechanic is familiar with the usual planer bed, which has V-shaped ridges on its under-surface, sliding in well oiled V-grooves in the supporting frame. A certain amount of power is necessary to slide this bed after it is started, and still more to start it. To render both the starting and the moving easier, it has been proposed to use grooves in both surfaces and provide a round shaft in each pair of grooves; such shafts to be revolved by the power which drives the planer, thus avoiding any standing friction of the bed on the frame at the end of each stroke. This device, although objectionable from other reasons accomplishes its object, and renders the planer bed free to move with the slightest touch. In short, when one surface is in motion with respect to the other, the two are practically in floating contact, and, unless restrained by flanges or grooves, they respond to force in any direction with equal facility. Every school boy knows that his sled pulls easier when started than at starting; also, that it pulls lengthwise the runners much easier in snow than crosswise them, but, that, on ice, where the surface is perfect, it will skid or slide sidewise, just as easily as forwards, if its runners do not present sharp edges to prevent such sidewise motion.

Behavior of a Skidding Car.—From the above examples, we are now in position to understand why an auto driver loses control of his vehicle, when it starts skidding. His wheels float freely in any direction, just as the sled on ice moves freely, and the car swerves to the one side, or the other, just as does the sled. Some recommend turning the steering wheels in the direction of the skidding movement, so that they may roll in that direction, in the chance that they may again secure their rolling (standing) friction, and so control the car, but this can hardly be done where room is not plentiful, and, where there is plenty of room, there is little danger from skidding. The general practice is to point the steering wheels in the desired direction, so that, if they do regain their grip, the car will proceed away from danger; this being also the most natural thing to do.

Primary Causes of Friction Loss.—Having now mastered the difference in friction between the rolling or standing wheel, and the one which, being in relative motion to the ground, *is floating*, we are ready to consider why the skidding begins *in the* first place. What causes the wheels to start floating or

slipping? There are a number of answers. If one brake applies much harder than the other, it may hold one wheel so hard as to retard it more than the vehicle is retarded, so that the balance gear (differential) drives the other faster than the vehicle, and so causes it to slip. With one wheel slipping and floating, the other may easily follow.

Balance-Gear Action.—If the engine is retarded, it tends to retard both wheels, and the one which is the most firm in its rolling friction tends, through the balance gear, to drive the other wheel opposite to the way in which the vehicle is moving, with the resultant slipping. The same result follows the application of a transmission brake. This tendency may readily be seen by driving with one wheel on the sprinkled greasy portion of a street, and the other on the dry portion, and suddenly retarding the engine and propeller shaft. The peculiar phenomena of one wheel spinning backwards (reverse direction) on the greasy street is not infrequent, and, with one wheel floating, the other may not be firm enough to hold the vehicle on its way. Both the above actions are more or less dependent on the balance gear, and would scarcely be found, if such a device was not in use. Similar results follow a sudden application of power, but this seldom happens on bad streets, where skidding is likely, since the average driver is cautious in such places.

Sudden Turns and Skidding.—Sudden swerving from the course will almost always produce skidding, if the conditions are favorable. This, also, is recognized and guarded against. It is the method used by the man who wishes to show off, or to get the sensation, but he is generally and properly careful to see that there are no curbs nor dry spots, into which the car can skid, and which would suddenly stop his sidewise motion, with, possibly, the breaking of a wheel, the bending of an axle, or the upsetting of the vehicle.

Unrecognized Causes of Skidding.—The dangerous skids are the ones which come without recognized cause, and which, on this account, are not to be prevented by any volition of the driver. A bit of freshly sprinkled street, or a stretch of ice thawing on top, may be the dangerous exceptions to an otherwise safe progress, which has not seemed to require tire chains, or studs. If the roadway is sloping, it is very easy for any small obstacle to start the vehicle to bouncing off the road, much as a rubber ball bounces, and, once started, the surface may be too slippery to permit it to stop.

Car Construction and Skidding.—In general, the cause of skidding is to be found in the construction of the vehicle itself; that is to say, in the distribution of the weight. While a certain proportion of weight is necessary on the steering wheels, in order to insure proper steering, it is a good general *proposition that* the majority of skids arise from the rear,

and are due to insufficient weight on the rear wheels. If one will put on a pair of skates, and try to push a load, he will find that his feet slide from under him with certainty, unless he prevents this by placing the skates crosswise, or doing some such stunt. But, if the load be carried, the tendency of the skates to slip is slight, and the load is carried easily. This is the usual cause of skidding. The front wheels are too heavily loaded for the amount of weight on the rears, and the propelling effort causes the rear wheels to slip backwards, and thus become floating, after which they float in any uncontrollable direction. Lightly loaded fronts may also skid easily, but the danger from this is not so great, since the fronts are not first caused to slip by the propelling or braking force.

Effect of Proper Weight Disposal.—Many experiments have determined this, and also shown that skidding seldom follows when the weight is properly disposed, and, particularly, when there is not a great preponderance of weight on the front end. A large amount of weight on the fronts may be thrown onto one wheel, or the other, by the inequalities of the road, and this results in an unequal or sidewise resistance to propulsion, which may push the rears to one side or to the other. Thus, if one front wheel strikes an obstacle, the inertia of the vehicle, and the propelling power, throws the mass around that obstacle, and unless the wheels hold their course, the result is a skid.

Long Wheel Base Advantages.—Just what proportion of weight should be on the drivers is hard to say, as the wheel base enters. The longer the base, the smaller the danger of skidding, from front-wheel resistance. But, it is safe to say that, future automobile makers will construct with greater reference to this important matter, as they learn that it can be largely obliterated by carrying the weight on the rears. This same placing of weight also stops slipping of the tires, and saves much rubber and tire expense. Or, in other words, it is cheaper to carry the load on the tires than to wear them out by the slipping, which follows pushing the load if it is carried on the front wheels. Both this matter of tire cost and skidding favor the use of three-wheelers, and the use of the three-wheeled vehicle, now largely confined to the motorcycle with its side-car, will doubtless find more favor in the future.

CHAPTER XXXV.

Starting Cranks, Mechanical and Self-Starters.

The Problem of the Self-Starter.— Like most problems of the automobile, the self-starter is one that appealed to inventors very early in the history of the industry. The heavy coiled spring to be wound up by the engine, and then held by a button, until wanted to start the engine again, was designed in 1896. The three-cylindered starting-motor, driven by a tank of compressed gas or air, and geared to the engine when wanted, was offered on the market in the very first years of this century. But, in those days, the buying public was not interested in starters. People were thinking of going and not of starting. They would get started somehow, but that they might continue to go after was the big problem.

The Magneto-Generator and Self-Starters.— Improved ignitions gradually brought the magneto into use, instead of the battery. Magnetos need to be "spun" to make a good spark for starting. "Spinning a motor" is hard work. Hard work made motorists reflect, and so the self-starter found immediate recognition following the advent of the magneto for ignition. Coupled with the magneto was the fact that engines had for a number of years been made larger and with more cylinders. This increase in size and complexity also made starting harder. The larger number of cylinders made a hard drain on the battery, where used, and so demanded the magneto for ignition. Thus, several of the improvements all helped to make the self-starter a necessity for the larger cars.

Self-Starters and Small Cars.— That the self-starter will be added to all cars seems very unlikely. Its complication seems too great to be warranted in vehicles of light weight and mechanical simplicity. But that a man should be compelled to get out into the street in the front of his vehicle, to start the motor, is also a condition that our engineers will not continue to permit. The probable solution will be that the larger and more expensive cars will use the complicated self-starter, and the smaller cars will use some mechanical starter that can be operated from the seat or from the side of the vehicle as the driver enters. The rapid growth of the lighter and simpler vehicle in recent years presages a still further simplification and lightening, and only the simplest forms of starters can be permitted on such

constructions. Naturally the simplest form of starter is the usual crank, and it is likely to continue in favor. So long as the engine is at the front with its shaft lengthwise the vehicle, the easiest place to apply the crank is at the front of the vehicle, but this is not handy for the user. There is some indication that, in time, the engines of the simpler vehicles will be again placed at the rear, where the work is to be done, and this may permit of the crank being brought to the side of the car, where it can be reached from the curb.

Geared Crank Starters.— Next to the direct crank some form of geared crank is most simple. The early Stevens-Duryea, Duryea and Olds cars had such geared cranks, where they could be reached while sitting in the seat or standing at the side of the vehicle, but buyers did not at that time appreciate such refinements and the simple and less expensive direct crank was substituted. The geared crank is easily applied to most present cars, and so a crank-starter can be easily applied, and will doubtless be used on many future light cars.

Rope or Strap Starters.— The next simplest form, and one used on early Duryeas and some Orients, is the rope or strap starter. This is a rope wound around a drum, and engaging the main shaft by a ratchet and pawl. A pull on the rope turns the engine. A spring returns the drum to its original position. With a small motor several turns may be given the shaft by a single pull. With a larger motor the leverage is arranged to suit the user and a smaller turning of the engine shaft is arranged for. The form used on the latest Duryeas was nearly as simple as a crank. This had a lever pivoted on the engine case hub and carrying a pawl which engaged notches in the fly wheel. Four notches were usually provided, but with the two-cylinder engine, to which this device was applied two notches were sufficient. From this pawl a spring wire ran around the fly wheel periphery and forward terminating in a rope which was fitted with a handle for the operator to pull. A spring returned the lever to its original position and the spring wire by its shape hung clear of the fly wheel when not in use. The pawl had a long rearward arm, which ran under a stop at the rearmost position and lifted the pawl out of the notch, in case of a back-kick or when not in use. Such a device is light, safe from back-kicks, and always ready. The rope can be pulled by a kick-pedal, if preferred. In delivery vehicle service the kick pedal is placed so that the operator, in mounting the car, can give it a kick and start his motor. A well known starting device along much the same lines is the Wilkinson. This has the lever and pawl and spring for returning, but, instead of the rope or handle, has a bell-crank and connecting link, the upper end of the bell-crank terminating in a pedal for foot operation. This device is specially designed for attachment to fly-wheels placed in the usual position under the foot board, and has been proven by a number of years of use. Several modifications of this device have come onto the market in recent years.

Spring Starters.— Several spring starters are now to be had. All of these embody the same general idea, and are usually made to be applied to the front of the engine, in the place of the starting crank, or around it, although it may be readily connected by chains or gears when the engine construction does not permit such attachment. Pushing a button releases the spring from the case and attaches it to the engine, which it turns over several times. So long as this button is held, the engine is turned until the spring has run down, by which time the engine has certainly taken up its action. After the engine has begun to work powerfully, the button is released, and the starter mechanism engages in such a way that the motor winds up the spring. When full wound, it automatically disengages from the engine, and is set, ready for the operator to again act, when another start is needed. The weak point of the spring starter is that the number of turns possible from a spring of moderate weight and size is limited. While it is usually of sufficient capacity to do the work required, there comes the inevitable time when the engine does not respond quickly and the starter exhausts itself. While this defect is found in any form of self-starter, the limit is probably reached in the spring and compressed gas starters more quickly than in the electric. Recognizing this defect, it has been often said that, when the engine is in perfect order, it starts so easily that no starter is needed, and when it is not a self-starter fails. Doubtless this belief long held back the adoption of the self-starter, because the buyer felt that, since he had to do the hard work when the starter failed, he could as well do the easy starting without this complication.

Air Starters.— The first starter to win favorable recognition was the Winton air starter the success of which did much to overcome the prejudice against starters, and, assisted by the requirements of the magneto-ignition and the many-cylinder engine-friction, is really responsible for the starter wave coming when it did. The Winton cars have always been fitted with a control, which makes use of compressed air, and so have had a pump for compressing this air. There was, consequently, but little additional cost or bother in adding a tank to hold a quantity of compressed air, and to fit pipes from this tank to the cylinders. In these pipes some form of valve was used to permit the air to flow at the time desired. A rotary valve was very popular with air starters, because it could be operated direct from the half-time shaft, and admit air to a cylinder during the early part of what should be the working stroke. Such air admission converted the engine into a 4-stroke cycle air engine for the time being. By admitting air only on the working stokes the suction and compression strokes were not interfered with, and the engine was free to take up its working cycle. When explosions began they generated sufficient pressure to prevent the compressed air from flowing in, and the engine could run without the air being shut off, and without wasting much, if any, of it. It was quite common to have small check valves in the air pipe outlets, so that the explosion pressure could not drive gas from the cylinders back into the air tank. Not that the pressure

or added gas would hurt anything, but that the heat might evaporate the oil packing of the rotary valve. The operator would close the starter control cock when the engine was started, and the air pump would pump up the tank as the engine ran. It was a clean simple system, with little cost or complication, but would not turn an engine as many times as the later electric method.

Gas Starters.— One of the very oldest forms of engine starter is that which introduces a charge by hand, and fires it; the resulting pressure doing the work of starting the engine. This was rather an adaptation from stationary engine practice. Several forms have been used on motor cars. A hand pump drawing mixture from a small carburetor and sending it to the cylinder, which is standing at the beginning of the working stroke, could be used to put a charge under some compression into this cylinder. With some additional means of making a late spark this charge could be fired. This method, while fairly well adapted to a single cylinder-engine, could not be followed fast enough on a multiple-cylinder; consequently, unless the first single impulse was sufficient to get the engine going, it was a slow process to repeat the operation.

Gas mixtures under compression made no very strong appeal to the average motorist. They required not only the same mechanism as the air-starter, but also, a method of making the spark very late. Other workers on gas starters made use of the acetylene gas tanks which many cars carried for lighting purposes. A little gas mixed with the air and lean mixture, drawn in on the suction stroke, would so enrich it that a fairly strong explosion would result. But, with all gas starters, the trouble was not only to get the chemical composition right for an explosion, but to get the spark on the working stroke, so as to secure an impulse that would send the engine forward. The complication and uncertainty of the gas starter was against it and no large numbers were marketed.

Electric Starters.— People were not slow to favor the electric starter. This had been proposed before the beginning of the century, but the need was not then felt. As first made, it was a small motor geared or chained to the engine by a wide reduction ratio, so that it could turn a refractory engine, and having means for allowing the engine to over-run, when it had started. It drew the current needed from a storage battery, provided for this purpose, or for combined lighting and starting. Details of the starting switches and disconnecting devices varied considerably, but, in general, this simple form was first adopted. Following it almost immediately came the inclusion of a dynamo for recharging the battery, and the two-unit set was complete. But, when the number of parts were considered, and the short amount of usage compared, it was seen that the complication was out of all proportion to the service rendered. Likewise the cost was high, and the weight considerable. Further, the space about the engine was taken up so fully, that accessibility was made difficult.

Motor-Generator Equipment.—These considerations brought about a further improvement, so that a single unit starter and charger, or motor-generator set, is now the practically accepted device. In these the same machine converts current from the battery into power, until the engine starts, after which it automatically changes its functions and furnishes current to the battery, and for lighting. These devices have had much study expended on them, and produce really wonderful results. The average gear ratio of such devices is about 3 to 1, and they turn the engine as high as 150 turns per minute, which is twice the usual hand cranking speed, while some forms will run the engine up to 250 turns per minute. They are, of course, limited by the battery supply, but some batteries are large enough to furnish current for actually propelling the car a considerable distance. Not only are these motor-generators compact and apparently simple, but they are not of excessive size and weight, some being as light as 20 to 30 lbs., while others are as heavy as 75 lbs. They are made in voltages as low as 6 and 12, ordinarily, although an occasional 24-volt outfit is found. For short periods, such as turning the engine over the first compression, they will stand very high loads of current, as much as 300 amperes being not uncommon, although they usually do their work at less than one-third this figure. Very ingenious devices for insuring safety from wrong currents are provided. In some constructions these consist of cut-outs, which shut off the current. In others, they vary the effect with the voltage, and so secure control. For example, the operator turns the battery current into the motor by a switch, pedal or lever, and the motor is forced into action. As the motor speeds up the automatic switch acts, and the motor becomes a generator, with a voltage higher than that of the battery, so that it begins to charge the battery. Voltage regulating cut-outs also protect the battery from overcharging. With high motor speeds there would be danger that excessive currents would do damage, but these are taken care of by double field windings in reverse directions. One of these windings is coarse and effective for starting mostly: the other is of fine wire, and, with the high voltage which accompanies high speeds, it exercises a considerable effect on the field core, keeping down the output, so that no damage results. When the motor speed dies down, a cut-out opens the circuit, and stops all current. In short, the electric motor-generator-starter has reached a very high degree of perfection and simplicity, when the many details of the problem are considered.

Meters and Meter-Shunts.— In connection with the starter some builders fit meters and others do not. By many the meter is regarded as an objection, because, if included in the circuit, it must be very heavily built to carry the starting current, and so not very sensitive in its indication of the charging current. It is also one more device, which may be a source of trouble; and its introduction into the working circuit means a distinctly smaller starting effort. But, without the meter, the operator cannot know that his battery is being charged, and may find *himself depending* on an empty thing when he next wishes

to start. To meet this need, Hoyt and other inventors supply a milvoltmeter of such delicacy that it may be put into a shunt circuit, forming a parallel portion of the conductor, between the battery and motor-generator. So small a current is carried on the shunt, that it is negligible, but it serves to indicate when current flows in the main conductor. If, for any reason, the meter becomes deranged, it affects in no way the flow through the main wire. It, therefore, combines the satisfaction of the meter, with the certainty of the no-meter wiring, and is another example of the perfection to which these constructions have been brought.

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